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ABSTRACT

The purpose of this study was to investigate the problems facing primary teachers in implementing the 5-14 guidelines for science and technology and the extent to which these problems are related to teachers' knowledge and understanding of the subject matter in Scotland. Data collection methods included questionnaires and interviews. A key finding was that many primary teachers lack confidence in their ability to teach the science and technology components of the environmental studies curriculum for pupils 5-14 and do not have a sound grasp of the ideas they are expected to develop in their pupils. Other findings include: teachers felt relatively more confident about the teaching of science process skills than about developing understanding of content; there were predictable variations relating to gender and possession of some qualification in science; teachers who had been qualified longer were more confident about teaching mathematics, English, and religious education while those qualified later were more confident about teaching science and technology; low confidence was associated with various factors including disliking science in their own schooling, inadequate initial training, little in-service help, and insufficient resources and support to cope with the practical difficulties; and those teachers who had studied some science in secondary school had a better understanding of science ideas. Contains 53 references and the survey instrument. (JRH)

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The Scottish Council for Research in Education

Confidence and Understanding in Teaching Science and Technology in Primary Schools

Wynne Harlen
Colin Holroyd
Michel Byrne

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Confidence and Understanding in Teaching Science and Technology in Primary Schools

Wynne Harlen
Colin Holroyd
Michel Byrne

SCRE
The Scottish Council for Research in Education

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Summary

Chapter 1
Context and purpose

Describes the policy research context of this study.
The research questions are posed and the research design outlined.

Chapter 2
Phases and methods

In *Phase 1*, 514 primary teachers responded to a questionnaire about their confidence. In *Phase 2*, 57 teachers were interviewed about their understanding of ideas in science and technology. In *Phase 3*, 33 teachers kept notes about theirteaching of science and technology and discussed these by telephone. In *Phase 4*, 30 members of staff in teacher education institutions, and a small sample of education authority advisers, were interviewed about the initial and inservice training of primary teachers.

Chapter 3
The teachers

The teachers who helped us in Phases 1, 2 and 3 are described in terms of their sex, the number of years since they qualified and the amount of science in their own educational backgrounds.

Chapter 4.1
Confidence

Primary teachers were less confident about teaching science and technology than about almost all other curriculum areas.

They were rather more confident about 'Living things and the processes of life'and 'Earth and space' than they were about 'Energy and forces' and design and control technology.

Teachers' confidence about developing science skills and processes in their pupils was higher than their confidence about developing understanding of science content.

With respect to science and technology teaching, male teachers were more confident than females, the more-recently qualified were more confident than the more experienced, and those with science qualifications in their own background were more con-fident than those with none. Although many teachers showed a high degree of general professional confidence, which allowed them to tackle science and technology teaching with some confidence that they would be able to cope, many were still not confident that their own understanding would be adequate to facilitate conceptual development in pupils.

Chapter 4.2
Understanding of Science

Understanding was analysed and reported in relation to ideas, not topics. The science ideas (derived from the 5-14 Guidelines) we looked at were found to differ considerably in 'understandability'.

Some were understood by all teachers; some by very few. Individual teachers varied widely in the level of their understanding across the ideas.

Many teachers possessed misunderstandings of those ideas they are expected to develop in their pupils. Development of understanding of some ideas took place very rapidly during brief discussion of situations in which they were applied; understanding of others developed much more slowly, or rarely.

Having some science in their own background made understanding of the ideas more likely, but did not guarantee it. There were some teachers with no science in their background who had managed to gain good understanding of the science ideas.

Chapter 4.3 **Understanding of Technology**

Teachers were often unclear about the nature and purposes of technology education in the primary school.

When they did not have a secure understanding of ideas in science, then the application of those ideas in technology was flawed.

The ideas of control and design technology were often familiar to teachers, even when the terminology was not. Teachers often possessed those understandings in technology which are dependent on the 'common-sense of everyday experience'.

Teachers tended to be satisfied with enjoyable practical experience in technology and to under-estimate its importance for developing ideas.

The Environmental Studies Guidelines made technology seem difficult to understand; in the examples we discussed with teachers technology was seen as simpler than expected.

Chapter 4.4 **Classroom Practice**

All the teachers we spoke to taught a fair amount of science and technology; what they taught was based on personal decisions rather than whole-school planning.

Teachers were very skilful at teaching in ways that minimised risk to their professional confidence.

The major source of difficulties was equipment/materials; however, one third of teachers had some difficulty with subject content.

Most teachers were satisfied with what they taught, but the criteria to judge this were not centred on conceptual development in pupils.

Chapter 4.5 **Help Wanted by Teachers**

Teachers saw themselves as needing a lot of help to teach science and technology effectively.

Teachers wanted help to develop their own understanding of ideas in science and technology, but this was not the only need they identified or even the priority need.

They requested: inservice training; print materials and resources; more time to think and prepare; more and better apparatus and equipment; specialist help and an extra pair of hands; school policies on timing, co-ordination and support; suitable accommodation. They recognised that better understanding of science and technology would increase their confidence that they were developing pupils' ideas in the right directions.

Chapter 4.6 **Initial and Inset Training**

In *initial training* the time given to science and technology was low. The amount of science/technology teaching during school experience varied very widely; for some students it was zero. The emphasis on content (i.e. on student understanding of the ideas of science and technology) had recently started to increase – but there was opposition to the pendulum swinging too far away from processes.

Most courses in both science and technology were based on practical workshops; coverage was organised in everything from short science and technology topics to huge environmental studies themes. A great deal of

material could not be covered; a lot of faith was placed on students' own learning. The need for differentiation had only recently started to be addressed in most courses; the greatest emphasis was on providing supplementary reading materials to enhance students' background knowledge.

Teacher education institutions provided few short inservice courses. Education authorities provided many short courses and other forms of *inservice* support; they were planning for a large increase in demand in the future. Short courses did not address the issue of teacher understanding. There were interesting developments in the provision of longer award-bearing courses; there was increased recognition that these need to deal with teacher understanding. An adequate national training and development programme would need extra money and sensitive, flexible, long-term planning.

Chapter 5
Teacher Profiles

This chapter provides profiles of six teachers, drawing on data from different phases of the research. Taken together these show the range of professional development needs.

Chapter 6
Key Issues

Seven issues we believe to be important are discussd around these questions. Primary teachers' confidence – is there a problem? Primary teachers' understanding – is there a problem? What level of understanding of science and technology is necessary? How are teachers' confidence and understanding related? What effects do low confidence and low understanding have on teaching? How should initial training be changed? What professional development of teachers is needed?

Chapter 7
Implications

In this final chapter we bring together some implications for action by five different groups concerned with science and technology education: headteachers and school management teams; teachers; policy makers; teacher educators and researchers.

1 Background, context and purposes of the research

Background

The inclusion of science in the curriculum of Scottish primary schools was accepted in the 1960s when the Scottish Education Department's influential Primary Memorandum, *Primary Education in Scotland* (SED, 1965) proposed the grouping together of separate subjects and the introduction of Environmental Studies. This report also emphasised a child-centred approach to primary education and advocated 'the provision for each child of an education suited to his age, aptitude and ability'. Thus both the subject matter of science and the methods through which it could be effectively learned were officially encouraged but it took many years before the aspirations of the Primary Memorandum began to be visible in the classroom.

Attempts were made to encourage science through the Scottish Education Department's (SED) support of the *Science 5–13* curriculum development project from 1968 and its successor, *Learning Through Science*, from 1978 to 1983. However these developments had impact only in a small proportion of schools, as revealed by the HMI report *Learning and Teaching in Primary 4 and Primary 7* (SED, 1980) which found that 'science fared badly, with 60% of all teachers giving it little, if any, place in their curriculum'. The inspectors criticised what work there was for lack of planning for continuity from one stage to another and the absence of whole school policies for environmental studies. Further attention to science was given through the publication by the Committee on Primary Education of *Towards a Policy for Science in Scottish Primary Schools* in 1981. In particular this urged schools to create their own policy documents for science and it endorsed the philosophy and material of *Science 5–13*. It did not, however, mention teachers' understanding of science as an issue, since its emphasis was on the development of skills and attitudes. 'Of course knowledge is useful but the particular information which certainly will be gained by the pupils is of less significance, educationally, than is their adoption of a problem-solving approach with all that this way of finding-out implies'(p4).

Detailed help in formulating and implementing a school policy for science was the outcome of the *Primary Science Development Project (PSDP)*, funded by the SED from 1981 to 1985. This project published a series of eight brief booklets on the rationale and approaches to science, links with other areas of the curriculum, class organisation, types of activities, science for the early years and for P4 to P7*, resources and record keeping, but no materials for direct use in the classroom. (*Primary Science Development Project*, undated). The rationale for this approach was that 'the project team believes that there are sufficient pupil resources of the type to foster good science education in the primary school on the market or in production. A priority need is considered to be support for teachers to assist them to make the most of these resources in the classroom and to assist promoted staff

* The seven years of primary education in Scotland are labelled P1 to P7 (age 5 to 12).

in the production of school policies.' (PSDP booklet 1, p3) The PSDP identified science as a method of enquiry and as a body of knowledge. It also recognised that in practical activities which involve 'model building', where pupils are asking questions and finding answers through experiment, and when 'what they have learned begins to influence their design and construction of the model', then scientific and technological development is taking place (ibid. p6). This is the extent of reference to technology in these materials. Indeed none of the documents mentioned so far, nor the curriculum materials, made any explicit reference to technology. However, many of the activities to be found in *Science 5/13* and in *Learning through Science* involved problem solving of the kind which would now be regarded as within the purview of technology.

One of the earliest references to technology in primary schools was by HMI in England and Wales (DES/WO, 1981) in the suggestion that 'more emphasis than at present should be placed on work in three dimensions and some of this might be of a simple technological kind aimed at designing and making things that work'. This was preceded by pioneering work of a few teachers, such as Evans, who published an article describing the devices created by ten year olds to solve problems (Evans, 1980). Although he took a rather narrow view of technology (as applied science) he distinguished it clearly from science as a process.

School-level initiatives in technology were also taking place in the early 1980s in primary schools in Scotland. The Consultative Council on the Curriculum's Committee on Technology affirmed in its final report (CCC, 1985) that 'it should not be thought that technology begins when children transfer from the primary to the secondary school. A number of schemes have been implemented in Scotland to engage primary school pupils in technology' (p15). This report, which argued strongly and successfully for technology to be a compulsory 'mode' of the secondary school curriculum, recommended that 'teachers in primary schools should be encouraged to introduce technological activities and should be supported in doing so by the provision of adequate resources' (p25). When the National Guidelines on *Environmental Studies 5–14* were developed, they provided continuity with the secondary modes of Scientific Studies and Applications, Social and Environmental Studies and Technological Activities and Applications, by identifying separately the skills and knowledge relating to Science, Social Subjects and Technology.

The *5–14 Development Programme* gave the opportunity for what the 1980 HMI report had called for, a complete review of the whole area of environmental studies (SED, 1980, p25). The report drew attention to the need to address the question of what could be realistically expected at the primary level. It also warned that 'they [teachers] also require guidance, but there is a danger that too much detail, too many objectives, may simply overwhelm and frustrate them' (ibid, p26). Finding the right balance between helpful guidance and frustrating over-prescription was clearly a challenge for the authors of *Environmental Studies 5–14* (SOED, 1993a), judging from the considerable changes between the draft version and the final guidelines and the extended time taken for this revision following consultation on the draft guidelines.

The structure of the Environmental Studies guidelines, as that for all five areas of the 5–14 programme, is described in terms of *attainment outcomes*, *strands* and

targets. Attainment outcomes refer to areas of understanding, which for science, are:

- Understanding Living Things and Life Processes
- Understanding Energy and Forces
- Understanding Earth and Space

and for technology:

- Understanding and Using Technology in Society
- Understanding and Using the Design Process

Each of these areas is further subdivided into three or four key features which are specified as content and context at three different stages: P1 to P3, P4 to P6 and P7 to S2.

Strands set out all the key aspects of learning in science, social subjects and technology. They are:

- Knowledge and Understanding
- Planning
- Collecting evidence
- Recording and presenting (science and social subjects only)
- Applying skills and presenting solutions (technology only)
- Interpreting and evaluating
- Developing informed attitudes.

Most of these strands are expressed as attainment targets at five levels, A to E. Attitudes are described in a more general way across all levels. The three bands used for describing the content and contexts for knowledge and understanding are reconciled with the five levels by defining achievement of level A as showing 'secure knowledge and understanding of those key features ... set out for stages P1 to P3' and level B as showing 'secure knowledge and understanding of those key features ... set out for P1 to P3 (and) steady progress towards development of understanding of the key features ... set out for stages P4 to P6' and so on. This device avoids the problem of spelling out in detail levels of development in each item of content. It also leaves teachers considerable freedom to plan topics to cover the content over a period of several years. However it is too early to evaluate the extent to which this solution has achieved balance between providing support and becoming a straight-jacket. The guidelines were published towards the end of the session 1992/93. At that time primary schools were in the midst of implementing the guidelines for English and mathematics and most were not planning to begin using the environmental studies guidelines before 1994/95.

■ Context

Concern about primary teachers' own understanding of concepts involved in teaching and learning science and technology has sprung from three main sources: reports of inspectors, research into children's learning and its implications for the knowledge needed by teachers, and research into teachers' perceptions of their own confidence and competence.

Reports of inspectors

HMI in Scotland commented in 1980 that the neglect of science 'shows clearly that many teachers at present lack an adequate knowledge of science (as they do not of history or geography, for example) and materials to help such teachers and training for them are essential if science is to be given its place' (SED, 1980, p47). A similar note was sounded at about the same time by HMI in England who reported that 'the most severe obstacle to the improvement of science in the primary school is that many existing teachers lack a working knowledge of elementary science appropriate to the children of this age' (DES, 1978).

More than a decade, and a considerable amount of curriculum development, later, the Audit Unit report *Standards and Quality in Scottish Schools 1991–2* (SOED, 1993b) indicated that 35% of primary schools needed to give more emphasis to science and 32% were in the same position with regard to technology. Moreover only in 60% of schools were the pupils achieving good understanding in science; for technology the figure was only 45%. Understanding was being developed in biological concepts and in designing and making working models. By implication there were deficiencies in understanding concepts relating to energy and forces, to earth and space, to control technology and to the design process.

The period covered by the Audit Unit report was before the national guidelines *Environmental Studies 5–14* were published in final form. The later HMI report *Implementing 5–14* (SOED, 1994a) was still able to comment only on English and mathematics. Thus it is too early for comment on circumstances which characterise effective implementation of the guidelines for science and technology in Scottish schools.

However in England and Wales, HMI had been able to review practice since the introduction of science as a compulsory core subject in 1989. In *Primary Matters* (OFSTED, 1994) HMI report on the findings of a detailed survey of 49 primary schools carried out in 1993. Although the report does not deal with teaching and learning subject by subject, there is clear relevance to science in the findings that there was a strong association between high standards of pupils' achievement and teachers' subject knowledge. 'In virtually all of the lessons where standards were good or very good, teachers' subject knowledge was judged to be satisfactory or good. Where teachers had good subject knowledge, they were more confident in planning and implementing learning tasks, more skilled in asking relevant questions and...more successful in providing demanding work for the more able pupils' (p3). Weak knowledge of the subject was reported as being a significant factor in low achievement of pupils. These lessons were characterised by concentration on transmission of factual information and a narrow range of work. The report also indicates some strategies being used by schools to share and strengthen subject expertise within the staff.

Children's learning and implications for teachers

Research into children learning science points less directly but nonetheless strongly to the role of teachers' knowledge of the subject. That pupils' ideas about scientific phenomena can be different from the accepted scientific view was well established by research with secondary pupils in the early 1980s (eg Driver *et al*, 1985). These 'alternative ideas' were shown to be non-generalizable and likely to obstruct subsequent learning. Later research into the ideas of primary school

children, now completed across the full range of science concepts, confirms that from the earliest age children are developing their own understanding of the world around them, whether or not they are taught science. These ideas are often at variance with elementary scientific concepts. Not only are they limited by the range of the children's experience and a tendency to take account of only some of the relevant factors, but they are often the result of faulty reasoning. The latter point has underlined the importance of paying attention to the way in which children investigate the world around them, to how they collect, interpret and apply evidence; that is, to the development of process skills. However for a teacher to help children develop their scientific thinking and understanding it is necessary to know not only what ideas the children have but how these differ from the scientific view. Only if the teacher knows the scientific view is (s)he in a position to extend the children's experience so that they modify their own ideas in the light of relevant evidence.

Moreover, lacking a scientific view does not mean that teachers lack any view. As have children, adults also have ideas formed from experience which may be unguided by scientific thinking. Adults, including teachers, may retain unscientific alternative views, which are often similar to those of children (Kruger, Summers and Palacio, 1990). When teachers hold the same views as their pupils they are in no position to help children modify their ideas. Further, teachers have been observed to teach incorrect ideas to children.

Thus primary teachers need understanding of the processes of scientific enquiry and of the concepts which enable us to make sense of the scientific aspects of the world around. But these are not the only types of knowledge necessary for effective teaching. It is important to know what it means to learn with understanding and how this differs from rote learning. A central aim of science education is to develop understanding of general principles which can be applied in making sense of new objects or events. However, development of understanding of general principles begins, for any learner, with familiar objects and events. Ideas are formed from studying the immediate environment and linking together related aspects, thereby producing broader concepts and principles of wider application and greater explanatory power. The process cannot proceed in the opposite direction since the broad principles are highly abstract and are meaningless unless they invoke the many real situations which they link together. Hence scientific knowledge of itself is not sufficient; a teacher must know how to help pupils build understanding from concrete experiences.

An answer to the question 'what do teachers need to know?' has been provided in an often quoted paper by Shulman published in *Harvard Educational Review* in 1987. Writing in relation to teaching science, he lists the following kinds of knowledge as being required by the teacher:

- Content knowledge – about science and of science
- General pedagogical knowledge – about classroom management and organisation that transcends subject matter
- Curriculum knowledge – the guidelines, national requirements, materials available
- Pedagogical content knowledge – about how to teach the subject matter, including useful illustrations, powerful analogies and examples

- Knowledge of learners and their characteristics
- Knowledge of educational contexts
- Knowledge of educational goals, values and purposes, including the history and philosophy of education.

It is significant that Shulman puts content knowledge first in this list, since several of the subsequent items depend on it. But what he emphasises is not so much the mastery of each and every aspect of a subject, as an understanding of what it is that identifies science; how the discipline of science differs from other disciplines; what are its boundaries, its limitations and the different ways in which it can be conceived. With this grasp teachers can develop pedagogical content knowledge which he characterises as building 'bridges between their own understanding of the subject matter and the understanding that grows and is constructed in the minds of students.' (Shulman, 1991). In this process, Shulman argues a central role for the use of analogies and metaphors and claims that 'the fundamental reasoning processes are analogical, not deductively logical'. But he recognises that analogies may not change pupils' ways of making sense of phenomena unless the teacher also takes account of pupils' preconceptions. In the context of this research and what is reported later, it is worth quoting a specific example used to make this point:

> You teach them about how the eye works, about how light bounces off the object and reflects into our eye, and about the lens. They seems to understand; they pass our tests. Then you interview the kids afterwards and say. 'Well, how does vision take place?' You find out they still believe exactly what they believed before the unit began: namely, your eyes send out these rays that bounce off the object, like radar or sonar or maybe electric eyes. The instruction didn't take, yet they all pass the test because they have mastered the right words to use in school, even though they don't for a moment believe or understand them.
>
> The preconception – the pre-existing analogy – overwhelms anything that you teach them directly unless you know enough about the existing prior knowledge to surface it, talk about it, compare what they think is going on to what is actually going on, and get them to deal with the contrast and the contradiction. (Shulman, 1991)

This passage reminds us that both knowledge of the subject matter and of ways of presenting it is not sufficient to help learning and that many adults, including primary school teachers, will have been left with their alternative ideas untouched by their science education.

Teachers' knowledge and perceptions of their own competence and confidence

It did not require in-depth enquiry to recognise that in general in the 1980s primary teachers lacked confidence in teaching science. There were constant references to this in the reports of HMI and in 1980 Whittaker published a study which showed, unsurprisingly, that confidence was particularly low in relation to physical science. Teachers themselves were ready to admit their concerns about teaching science. It was later in the 1980s that research attempted to enquire into teachers' actual understanding of the science content rather than their felt confidence and perceptions of their competence in teaching it.

Most of these studies dealt with science and not with technology. As in the case of similar studies of pupils' understanding, they have each had a focus on a specific concept area, such as force (Kruger *et al*, 1990), energy (Summers and Kruger, 1992; Summers and Kruger, 1993), changes in materials (Kruger and Summers, 1989), gravity on the Moon (Noce *et al*, 1988), gravity and air resistance (Smith and Peacock, 1992), electric current (Webb,1992), astronomy (Jones, 1991) (Mant and Summers, 1993), phases of the Moon (Targan, 1987) and the greenhouse effect (Boyes and Stanisstreet, 1993). The general finding across all these studies, carried out not only in the UK but in the US, Australia, South Africa, and Italy has been that the explanations which many primary teachers could give of the concepts were at best incomplete and in many cases showed the same misconceptions as have been found to be held by secondary school students.

Perhaps these findings are not all that surprising for two reasons. First, that primary teachers are recruited, by and large, from those for whom science was not a strength in their own achievement at school and their experience in the intervening time has done little to increase their achievement in this area. Second, that the methods used to assess teachers' knowledge of science were similar to those used with school students, complete with their association with previous failure and frustration. However, even though the methods used may be valid for assessing the adults' scientific knowledge, they are less valid in terms of how teachers may deal with matters relating to science content which arise in the classroom. Teachers acquire pedagogic skill and knowledge which enables them to handle children's questions and to lead the children to an appropriate level of understanding even though they may not themselves have a high level of understanding of the concepts involved.

Research with teachers in training lends support to the ideas that confidence to teach does not depend entirely on understanding of the scientific content. Gooday *et al* (1993) administered a questionnaire to first and fourth year BEd students, asking them, inter alia, to rate for each item in a list of various scientific concepts, their own understanding, their ability to explain it to children and its importance for children. The questionnaire also asked about the student teachers' confidence in teaching science and technology, about their attitudes to science and technology and about their own understanding of certain scientific ideas. The results showed that, compared with the first year students, the fourth year students were considerably more confident in teaching science, were more knowledgeable about classroom resources and how to use them and had greater understanding of science processes. At the same time the understanding of basic science concepts was little different in the first and fourth year students. It could be inferred from these results that the development of pedagogic skill (perhaps mostly general but some relating to content, to use Shulman's categories) and the experience of practising in the classroom had increased confidence in teaching science, despite little change in personal knowledge. As Gooday *et al* comment, it is necessary to question 'whether the confidence of the fourth year students is relatively misplaced in the light of their generally poor understanding of a range of scientific concepts'. It also reminds us that there may be a considerable difference between self-expressed confidence and actual competence.

The research of Bennett, Wragg and Carré at the University of Exeter underlines the view that the issue of background knowledge in primary teaching is more

complex than whether or not the teachers have certain concepts (Carré and Carter, 1990). They asked a random sample of over 900 teachers in England about how competent they felt to teach various subjects of the national curriculum in 1989 just after it had been introduced. Science was ranked eighth out of ten subjects, with technology as tenth in terms of teachers' feeling of competence in teaching. In a follow up survey in 1991 of over 400 teachers, technology remained at tenth but science had risen to the third place after English and mathematics. The researchers ascribed the significant positive change in the teachers' perceptions of their own competence in science to the allocation of resources, both human and material to science teaching, together with the comprehensive map of the subject set out in the statutory orders (Bennett *et al*, 1992; Carré and Carter, 1993).

Much less research has been carried out relating to technology than to science. What there is suggests that teachers' confidence in this area is even lower than for science. The Gooday *et al* study showed less difference in confidence of first and fourth year students in relation to technology than to science. However, it was noted that there was less time spent in the course on technology than on science. The surveys by Bennett *et al* found that design and technology was the subject where teachers judged their competence to be least of all subjects in the curriculum and this did not change between the surveys in 1989 and 1991. Teachers reported that they continued to find difficulty in understanding design and technology whilst confidence in teaching science had apparently improved during the same time.

However, it would appear that the 'understanding' involved in technology is a more complex matter than in the case of science. It is not only teachers' own understanding of the contexts and content of the subject (as in the case of some areas of science) but equally problematic is their understanding of what the subject comprises and the aims and objectives of teaching it. To many teachers technology is a word introduced into the curriculum without clear meaning and boundaries. This is not an issue for primary teachers only. Foremost among concerns about technology in secondary schools, the Scottish CCC recently noted that 'there appears to be no clear and generally shared view in schools about the nature and main purposes of technology education', (Scottish CCC, 1994). The knowledge base required by the attainment outcomes for technology in the *5–14 Guidelines* derive from science, the social subjects and the experience of everyday life. Existing research provides little guidance as to the relative impact of these types of knowledge and of the understanding of the nature of technology on the confidence of primary teachers.

■ Purposes of the present research

The research thus took place against the background of the specification for the first time, in the *5–14 Environmental Studies Guidelines*, of the areas of understanding in science and technology which pupils should acquire in the primary school. It was also in the context of concern, supported by research, that teachers' own understanding was poor in the areas they were expected to teach. The project began a month before the publication of the guidelines and preceded the inservice and supply of support materials which became available in 1995.

Despite the arguments for emphasis on knowledge of subject matter to inform teaching and the insistence of the UK government that the proportion of subject

study for primary teacher trainees should be increased, there are also strong arguments that personal knowledge alone is not enough for effective teaching. Morrison (1989), for example, claims that other kinds of knowledge, about children's learning and how to help the development of abstract ideas in any subject are equally as important as subject knowledge. Moreover, no teacher, however knowledgeable, will be able to answer all the questions that primary pupils are likely to ask; nor should they necessarily try to answer all pupils' questions.

A teacher's view of learning may influence the extent to which lack of personal knowledge is perceived as a problem. If the teacher's role is seen as one of transmitting factual knowledge, then lack of this knowledge is perceived as a problem. If the teacher's role is seen as one of helping children to test and develop the ideas they bring to their scientific activities, the possession of factual knowledge is of less significance than the skills of gaining access to children's ideas and skills and of knowledge of techniques for developing them. The latter, constructivist, view does not argue for dismissing the importance of teachers' knowledge, for clearly the teacher has to know when pupils' ideas need to be challenged, but it does place emphasis on the understanding of the general direction of development – on the 'big ideas' of science, rather than on a knowledge of facts. It was considered important in this research to place emphasis on teachers' understanding of some of these 'big ideas'.

The research was designed to address the following areas of enquiry and research questions within them.

Teachers' understanding of the concepts in science and technology embodied in the 5–14 Environmental Studies Guidelines.

1 To what extent do teachers understand the key features of the attainment outcomes of the 5–14 guidelines in science and technology?

Teachers' current experience of teaching science and technology and their confidence in their own understanding of the concepts involved

2 How is the teaching of science and technology organised in the classroom?

3 How do serving primary teachers perceive their competence in helping children to achieve the attainment outcomes in science and technology?

4 What are the reasons for the perception of low competence and what are seen as being required to improve competence?

Problems relating to their own understanding of science and technology which teachers encounter in classroom practice

5 What aspects of pedagogy relating to teaching science and technology do teachers find more and less difficult?

6 What is the nature of difficulties which teachers experience in practice in teaching science and technology?

The provision made in ITT courses for development of teachers' own understanding in science and technology. Teachers' experience of initial training for teaching science and technology and of the help currently available to supplement their knowledge where necessary

7 To what extent do initial training courses provide for teachers to develop their own understanding of science and technology?

8 What help do teachers receive from initial and in-service training courses in developing appropriate pedagogical skills?

9 What changes in pre-service teacher training and in other forms of help, are likely to improve primary teachers' knowledge, confidence and practice in teaching science and technology?

There was an additional question which it was possible to explore on account of conducting part of the research at the same time as a science survey being carried out for the Assessment of Achievement Programme (AAP), and using the same sample of schools as taking part in this survey:

10 Are there any associations between teachers' expressed confidence in teaching science and pupils' performance in AAP science tests?

Research design

General considerations

Addressing the research questions required information from teachers and from teacher education institutions. Ideally if would have been helpful also to have been able to study classroom practice, but the resources available precluded this and instead we asked teachers to keep records and report to us on their teaching in science and technology during a three month period, noting particularly any difficulties they had encountered.

A research design was chosen such that some findings were from a representative sample of schools and could thus lead to generalisable conclusions. The questionnaire survey was carried out at the same time as the Assessment of Achievement Programme (AAP) in science in 1993, using the same sample of schools. Complementing this survey, information of different kinds was gained by individual interviews with a smaller and less representative sample of teachers and by follow up telephone interviews about their classroom experience with as many of these teachers as were willing to help further.

Since it was not possible with the resources available to involve teachers throughout the primary school the decision was taken to concentrate on teachers of pupils in P6 and P7 on the grounds that the influence of teachers' knowledge may be greatest at the top of the primary school where pupils' work involves deeper scientific and technological understanding. However the opportunity offered by using the AAP sample of schools, where pupils would be tested in science in P4 and P7, of investigating possible associations between information from teachers and the performance of pupils, suggested that it would be useful to include P3 and P4 teachers in the survey.

Phases of the project

The data gathering was designed to take place in four phases, with information relating to a particular research question often being derived within more than one phase.

Phase 1

A questionnaire survey of P3, P4 , P6 and P7 teachers in all the primary schools taking part in the science survey. Details of the schools and teachers taking part and of the rate of return are given in Chapter 2 and Chapter 3. The questionnaire was designed to provide background information about teachers' experience and training and aspects of classroom practice and enquire into how teachers perceive their competence in teaching various subjects of the curriculum and, within science and technology, the level of their confidence in helping pupils to achieve certain selected skills, knowledge and understanding. (Research questions 2, 3, 4, 5)

Phase 2

Interviews held with a P6 and a P7 teacher from 30 schools selected from the questionnaire sample to provide a range of practice and of levels of confidence of teachers. The interview probed understanding of the science and technology involved in six situations which were presented with the help of equipment or photographs. Teachers were also asked about the ease or difficulty in teaching the ideas to pupils. Each teacher was asked about three of these situations, so that about 30 responses were obtained for each one. Details of the form of this interview, described as 'collaborative explanation' are given in Chapter 2. (Research questions 1, 5)

Phase 3

Teachers taking part in the interviews were asked if they would further assist by keeping a note of their teaching in science and technology for a period of about 10 weeks and a record of problems encountered on forms provided by the project. Many agreed and some were replaced by other teachers in the same schools who volunteered to help. At the end of the period the teachers were interviewed by telephone, talking through their notes, which some also sent to the project researchers. Details of this phase are also given in Chapter 2. (Research questions 5, 6)

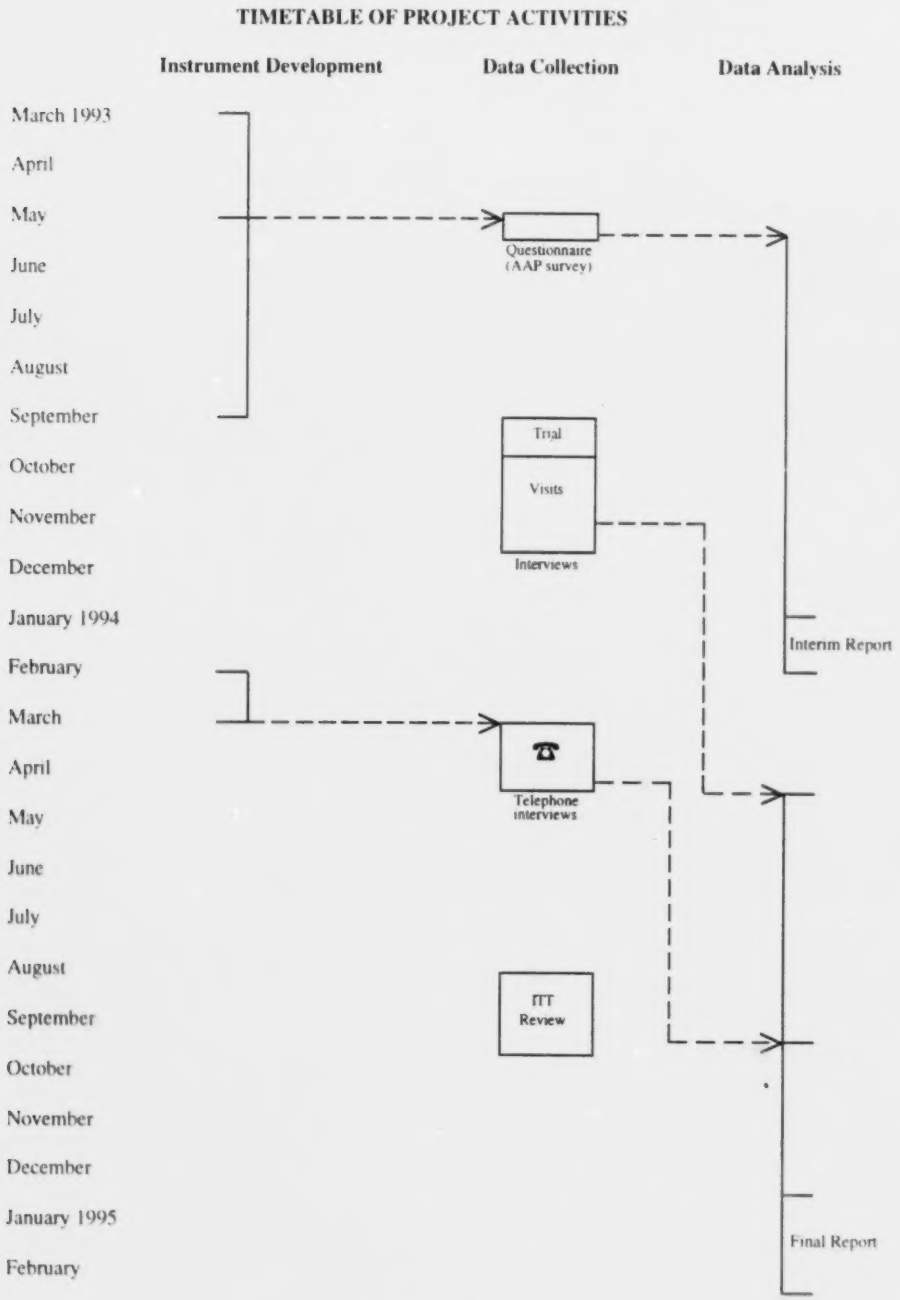
Phase 4

All institutions providing pre-service courses for primary teachers were visited and relevant staff interviewed about both the pre-service and in-service courses provided in primary school science and technology. Documents relating to these courses were collected. In addition interviews were held with selected education authority staff providing inservice courses for teachers in their regions.

In addition, the AAP science results for the schools in the questionnaire survey were used to explore variations in pupil performance in relation to variation in teachers' confidence and perceived competence in teaching science. Anonymity was preserved by relating these data through school numbers. The analysis was carried out by the AAP Central Service Unit, which analyses the AAP pupil data. The results are given in Chapter 4.1. (Research question 10)

Timetable

The research took place between the beginning of March 1993 and the end of February 1995. The timetable was as follows:



2 What we did ...

Phase 1: survey by questionnaire

In this phase information was sought about teachers' confidence in teaching various aspects of the primary curriculum, and particularly in science and technology.

A survey of primary school teachers in Scotland was carried out by questionnaire in May 1993. With the valuable co-operation given by the directors of the third Assessment of Achievement Programme Science Survey it was possible to send questionnaires to the 119 primary schools taking part in that survey. This was done with the permission of the directors of education of the appropriate regions. Headteachers were asked to distribute the questionnaires to teachers of pupils in P3, P4, P6 and P7. The aims of the project were outlined to these teachers and they were assured that information would be treated in the strictest confidence; completed forms were placed in sealed envelopes by the teachers and returned to us via headteachers. This sample of schools was used with the intention of exploring any link between teachers' questionnaire responses and pupils' performance in the AAP tests.

The questionnaire

The five-page questionnaire (see Appendix 1) contained three main sections: (1) background information, (2) teaching across the primary curriculum and (3) teaching science and technology.

1 Teachers were asked to provide information on their sex, the stage taught, any particular responsibilities (e.g. for a specific curriculum area), their teaching qualification and when it was obtained, qualifications in science gained before their pre-service training, experience of in-service training in science/technology, the number of years in teaching, and any employment experience outwith teaching.

2 Teachers were asked to give an estimate of their confidence in their knowledge and teaching skills in different areas of the primary curriculum. Each of eleven areas was rated on a four-point scale from 'fully confident in my knowledge and skills' to 'I need help to develop my knowledge and skills in this area'.

3 In the third and main section teachers were first asked how confident they felt that they had the knowledge needed to help develop pupil understanding of 26 different 'key features' of science and technology. These were quoted from the *5–14 Guidelines for Environmental Studies* (SOED, 1993a). Six items were from Understanding Living Things and the Processes of Life; seven from Understanding Energy and Forces and six from Understanding Earth and Space. Four items came from Understanding and Using Technology in Society and three from Understanding and Using the Design Process.

Teachers were then asked about their confidence in helping pupils achieve a sample of ten attainment targets in certain science processes: planning, collecting evidence, recording and presenting, interpreting and evaluating. The next question sought teachers' views on how difficult they found 13 professional skills that are involved in teaching science and technology. The final question was an open-ended one seeking information on the help that teachers felt they needed in relation to science and technology.

The sample

Replies were received from 99 schools, ie 83% of the AAP sample of 119. It is not possible to give a precise figure for the return rate from the teacher population targeted since the exact number of possible respondents in each school is not known. Five hundred and fourteen individual responses were received; this is estimated to be approximately 93% of the total number of P3, 4, 6, 7 teachers in the schools from which questionnaires were returned. Thanks to the strategy of co-operation with AAP, these response rates are unusually high for a questionnaire survey. It is interesting to note that the 1991 survey of primary schools in England and Wales drew on information from 433 teachers in 131 schools; this represented a 40% response rate in terms of schools approached (Bennett *et al*, 1992).

The AAP sampling produces a stratified random sample of Scottish primary schools in which small, rural schools are slightly under-represented. It is thus not inappropriate for us to claim, given the response rates achieved, that our respondents form a reasonably representative sample of the P3, 4, 6, 7 teachers in Scotland. Our findings from this survey can be generalised with a fair degree of confidence to the whole population of these teachers.

■ Phase 2: interviews in schools

This central phase of the research was designed to answer the main research question posed in Chapter 1, p.10. To what extent do teachers understand the key features of the attainment outcomes of the 5–14 guidelines in science and technology?

In the original research proposal it was argued that the use of written questions, similar to those used in exploring pupils' understanding, was unacceptable in this context. Instead data would be gathered by individual interviews with a sample of teachers. It was proposed to base these 'on a series of photographs of objects or events involving concepts in science and scientific concepts applied in technology'. It was envisaged that there would be two sets of questions and photographs dealing with different concepts from the 5–14 guidelines and that in any one school, one set would be used with a P6 teacher and the other set with a P7 teacher. This would have the advantages of reducing the possibility of conferring between interviews and of extending the coverage, whilst keeping the interviews to a reasonable length. It was expected that interviews might last for up to one hour.

Our central purpose was to describe teachers' understanding. We would be researching in an area where teachers on the whole are lacking in confidence; it was thus likely that our purpose would be misconstrued. Teachers might think they were going to be tested and perhaps judged as inadequate; they might feel anxious about how they would *feel* during the interviews. They might anticipate that the process would be disconcerting and cause them to question their

professional competence. There were other factors to be borne in mind.

(a) We could not be certain that our teachers would be genuine volunteers; they would be nominated by their headteachers and we could not be sure that they would have felt able to refuse.

(b) The teachers would not be known to us in advance; there would be no opportunity to build up a rapport before the actual encounter in school. (In other research on this topic the subjects were participants in an in-service course provided by the researchers. See, for example, Kruger and Summers, 1989; Kruger, Summers and Palacio, 1990; Mant and Summers, 1993).

(c) We were very keen to retain the goodwill of teachers as we wanted them to co-operate with us in Phase 3 of the project.

We took particular care that printed material sent to the school gave detailed information about the purpose and procedures of the interviews and gave this in as positive and supportive tone as possible. Similar care was taken over telephone conversations with headteachers and others. We wanted the actual process of interview to be non-threatening at least; if it could be positively enjoyable, so much the better. The procedure devised is described in pages 19–20 of this chapter.

The subject content of the interviews – science

The project was required to explore understanding of concepts in science and technology that related to the *5–14 Environmental Studies Guidelines* (SOED, 1993a). The 'key features' for knowledge and understanding in science (*Guidelines*, pp16–21) list what pupils should study and the 'contexts and content for developing understanding'. These 'contexts and content' descriptions tend to mix topic/content area to be covered with activities to be experienced and with outcomes to be sought. This has led to the judgement by some that the clarity of objectives within knowledge/understanding has been fudged. (See, for example, Bryce, 1993.) Whether this judgement is accepted or not, the guidelines do not describe or prescribe *concepts* that are to be understood.

The questionnaire used in Phase 1 made use of a selection of the 'key features' of science and technology listed in the guidelines. It was decided that six of these should form the basis for topics to be explored in interview. Taken together these six represented the three broad attainment outcomes, stages P4/6 and P7/S2 (with an emphasis on the former) and key features about which teachers had expressed (via the questionnaire in Phase 1) a wide range of confidence levels. They are shown in Table 2.1 overleaf.

We then designed six 'events'. These related clearly to the key features as explicated in the guidelines; each was planned to be seen by teachers as relevant (to the guidelines) and as potentially useful (for them in their teaching). In addition the 'events' only made use of materials that were reliable, cheap and easily transported. Each event would provide a topic for discussion in the interview. (See Table 2.2 on page 16) It can be claimed that each event/topic involves a general concept: skeletal movement; greenhouse effect; reflection; water cycle; evolution; flow of electricity. At this stage of the work attention was given to identifying the 'big science ideas' underlying each event/topic. These are described in some detail in pages 18–19.

Table 2.1: *'Key Features' for interview topics (science)*

Key Feature	Attainment outcome	Stage	Level of Teacher Confidence
– structure and functions of the major parts of the body as they relate to the processes of movement (muscles, bones and joints) ...	Understanding Living Things and the Processes of Life	P4/P6	High
– adaptation to the environment over a period of time, leading to an understanding of the process of evolution and the survival or extinction of species	Understanding Living Things and the Processes of Life	P7/S2	Low
– mirrors and reflections, including curved mirrors	Understanding Energy and Forces	P4/P6	Low
– construction of battery operated circuits	Understanding Energy and Forces	P4/P6	Low
– the water cycle (in simple outline) introducing water as a gas, melting, freezing, evaporation, condensation	Understanding Earth and Space	P4/P6	High
– fossil fuels: occurrence, combustion and effects of emission of 'greenhouse gases'	Understanding Earth and Space	P7/S2	Low

Table 2.2: *The six science 'events'*

	Title	Event
A1	ARM	The interviewer held his/her arm parallel to the ground, at right angles to the body and moved the forearm in and out.
A2	CARBON DIOXIDE	A page from a children's book, showing a coal-fired power station and with a small amount of accompanying text was examined. (The text was about carbon dioxide as one of the greenhouse gases.)
A3	MIRROR	A small object (a model dinosaur) was placed in front of a flexible mirror. (Two small plane glass mirrors were also available.)
B1	WATER	Water with cubes of ice in it was poured from a thermos flask into a small, shiny-sided tin.
B2	FISH	Two large, laminated colour photographs of very different fish (flounder and tuna) were displayed.
B3	CIRCUIT	A selection of simple circuits was set up; in some the bulb lit, in others it did not.

The subject content of the interviews – technology

The aims of the project included the description of teachers' understanding of technology as well as of science concepts. For each science 'event', we designed an extension into an area of technology that was loosely related to the science topic but which did not imply that technology was necessarily or simply the application of science (Table 2.3). Each technology extension was related to one or more of the key feature statements about technology that had been included in the Phase 1 questionnaire. These extension topics required little additional material/apparatus.

Table 2.3: *The six technology extensions*

A1	ROBOTIC ARM	– simple relationships between the way people control their movements and the way control technology helps to produce automated systems to control the environment.	P4/P6	Understanding and Using Technology in Society
A2	CHIMNEYS	– control of the environment (monitoring flue gas emissions).	P7/S2	Understanding and Using Technology in Society
A3	MIRROR-DESIGN	– the different stages in the design process and strategies they can use within these stages.	P4/P6	Understanding and Using the Design Process
		– the needs of particular groups in the local community.	P4/P6	Understanding and Using Technology in Society
B1	RAIN-GAUGE	– the merits/demerits of simple against sophisticated designs.	P4/P6	Understanding and Using Technology in Society
		– the different stages in the design process and strategies they can use within these stages.	P7/S2	Understanding and Using the Design Process
B2	FISH-DESIGN	– knowledge of a range of contexts within which the design process may (or may not) be applied.	P7/S2	Understanding and Using the Design Process
B3	KETTLES	– ways in which control technology can be used to provide various levels of control or automation.	P7/S2	Understanding and Using Technology in Society

We were aware that there was a greater disparity of views about the nature of technology than of science and that our findings in this area were likely to be more tentative. The main concern was to find aspects of technology that were clearly related to the guidelines and about which teachers would easily find something to say.

'Big Science Ideas'

The *5–14 Guidelines* indicate what pupils should study; they often do not give much illumination as to the conceptual understanding that should be built up. For example, pupils should cover the topic 'planets of the solar system': it would trivialise science if the expected outcome of the 'coverage' were to be no more than listing the names of the planets in order of increasing distance from the sun. We therefore took each of the key feature statements and the science event/topic related to it and attempted to explicate the 'big science ideas' which underpinned them and which it was hoped pupils would develop through studying the topics. By 'big science idea' we meant a propositional statement from the substance of science which was important to the explanation of this and a range of related events and phenomena.

The three or four big ideas identified by the team for each of the six science 'events' were subjected to validation by others with relevant professional and academic expertise: members of our advisory committee and seven independent experts. All of the latter replied in writing and lengthy discussions ensued with two of them. The responses we received confirmed our hopes that we were on the right lines and that it was worthwhile continuing the approach. We were able to incorporate the main points raised in a revised formulation of the ideas and to settle on three 'big science ideas' for each of the six science topics.

The big science ideas that we used in the analysis were as follows:

A1	ARM	1	Bones move at a joint, because of muscles.
		2	Muscles pull; they do not push.
		3	Muscles need to be in pairs to reverse a movement.
A2	CARBON DIOXIDE	1	Carbon dioxide is produced when fossil fuels are burned.
		2	Carbon dioxide in the atmosphere acts like the glass in a greenhouse; the temperature is higher (things get hotter) 'inside'.
		3	It is easier for light energy from the sun to get in through the carbon dioxide/glass than it is for heat energy to get back out again.
A3	MIRROR	1	To see an object, light from it has to enter the eye.
		2	To see a reflection, light from the object bounces off the surface of the mirror before reaching the eye.
		3	The brain 'assumes' that light has followed a single straight line (from behind the mirror), even if it has been reflected on the way.
B1	WATER	1	Water (as a gas) in the air changes to a liquid when it meets a cold surface.
		2	Water can exist as solid, liquid or gas.
		3	Gas changes to liquid when heat/energy is taken out; solid changes to liquid when heat/energy is put in.
B2	FISH	1	Differences observed in living things are helpful in the different environments in which they live.
		2	There are chance differences within a generation that can be transmitted to the next generation.
		3	Evolution occurs over a period of time, because of the selection of those inherited differences which are helpful for survival.

B3 CIRCUIT 1 For an electric current to flow, there has to be a circuit of materials, each of which allows electricity to flow quite easily.
2 Switches make (complete), and break, the circuit.
3 The battery supplies electrical energy which the bulb changes to light/heat energy.

Four comments on these big science ideas:

(a) It is convenient, but artificial, to have three ideas for each topic; clearly it is possible to expand the number considerably by rewording at a more detailed level.

(b) The ideas are given in a particular order; this order suggested itself to us by anticipating how the interviews were *likely* to proceed. The order adopted is not meant to imply some judgement that the ideas *must* be presented in this way or that they are in some necessary hierarchy of difficulty. We return to this point later.

(c) In formulating these ideas, we were always aware of the tension between accuracy and clarity; it is always possible to produce alternative and better wordings.

(d) Frequently our consultants made suggestions that seemed to us interesting, but not on the same scale of importance as the ideas that received general support. For example, one person was very sure that the idea of the human arm acting as a lever was a key concept that primary pupils should acquire. We were unconvinced, so in this case (and the others) we included the idea in a list of supplementary points that we would look out for when it came to analysis of the interviews (see Section 4.2).

The interview structure

In any one school, interviews were conducted with two teachers; one on three topics (Arm, Carbon Dioxide and Mirror) and the other on the other three (Water, Fish, Circuit). Each teacher thus had one topic from each of the three science attainment outcomes including one topic about which teachers in general had said they were confident. We varied the order of the two groups of interview topics and the sequence of the topics within each group.

The principle governing the design of the interview procedure was that evidence of understanding would emerge from people's explanations of the events. As mentioned earlier, we also wished to minimise the possible discomfort of those interviewed.

Each interview had the same general structure.

1 *Preamble*
- to help reduce tension, to establish rapport and trust
- to check on teacher understanding of the purposes of the research
- to give an assurance of anonymity in all reporting
- to seek approval to tape-record.

2 *Introduction* (for each topic)
- to relate the topic to the guidelines.

3 *Observation* – to focus the teacher's attention on the event, picture or whatever
– to ask them what they *observed*.

4 *Explanation* – to elicit from the teachers an explanation of what they have observed.

This was seen as the crucial phase of the discussion of each event/topic. Interviewers always started this discussion in a standard way. Alternatives were prescribed:

either (i) 'Why is it like that? If you can explain, fine. If not, I'll have a go ...'

or (ii) 'How can we explain that? Will you start, or shall I?'

5 *Prior understanding* – to confirm to the teacher the big ideas that were being sought and then
– to gain the teacher's view as to how their understanding had changed, if at all, during the discussion.

The importance of this phase was strongly stressed. The interviewers followed the script exactly for this phase. For example, they said ... .

'How, if at all, did your understanding change during our discussion?'

And *not* things like ...

'What did you learn from me during that discussion?'

6 *Teaching* – to obtain teachers' views as to whether the big ideas we had just confirmed were difficult, or not difficult, to develop in pupils
– to seek the reasons for these views.

7 *Technology extension* – to gain information from teachers which would allow us to describe the extent of their understanding of some simple aspects of control technology and of the design process.

This was introduced with a phrase such as 'While we are in this general area, let's look together at an aspect of technology suggested by the guidelines ...'. If time allowed we prompted teachers to talk about the ease or difficulty of developing these ideas in pupils.

8 *Support requested*

We tried to find time to reinforce the idea that the project aimed to be able to help teachers; we hoped to be of practical value. Teachers were asked what help/support they would particularly welcome. Information gained supplemented the data obtained from a similar section in the questionnaire in Phase 1.

Episodes 2 to 7 were repeated twice, ie they applied to each of the three science ideas in an interview.

Having devised this research technique, we then christened it **collaborative explanation.**

Piloting the interview procedure

Schedules, with some scripted sections, for the interviews were developed by trial and discussion within the research team. A kit of materials/apparatus was

assembled. A trial was then arranged in a primary school which was not going to be part of the main sample. The general strategy was discussed with the headteacher; each interview type was trialled on a P6 or P7 teacher from that school; the headteacher and the two trial teachers then discussed the procedure with the researcher. As a result of this, minor modifications were made to the schedules and to the scripted parts within them. Overall the procedure was judged to have worked effectively and the decision was taken to go ahead with the strategy as planned. We did realise that the pilot teachers were particularly positive about co-operating with us and that there might well be teachers with whom the approach would work less well.

The interviewers

The interviews were conducted by three people: the project research officer and two experienced primary teachers. To ensure consistency of approach a full training day was held and the early interview tapes were centrally monitored. There were differences in style and emphasis but the three interviewees were able to implement the collaborative explanation technique. A de-briefing day was held after the interviews were completed; feedback from the interviewers was noted and has been fed into the 'findings' sections of the report. It was a cause for satisfaction that, although the interviews took place at a time when there was great concern about teachers' workload and in several regions there was a 'flu epidemic, the interviewers had been welcomed into schools and had experienced unfailing courtesy and helpfulness.

The sample: schools and teachers

Interviews were conducted in schools in six regions of Scotland which together provided a good variety of schools, accessible to the researchers at modest travelling distances (see Table 2.4). Permission was obtained from directors of education to approach headteachers of schools we selected in the following way.

Table 2.4: *Distribution of schools by region/division*

Region	Division	Number of Schools
Strathclyde	Ayr	3
	Dumbarton	2
	Glasgow	5
	Lanark	3
	Renfrew	2
Borders		2
Central		3
Tayside		4
Grampian		4
Highland		2
	Total	30

Questionnaires returned in Phase 1 were sorted by region. From the schools in the six regions, a number were chosen to be approached for interviews according to two criteria:

- two or more questionnaires were from P6/P7 teachers
- responses to the open-ended question (No 11) indicated some recognition that help with the teaching of science/technology would be appreciated.

Approval was then obtained from the headteachers of thirty schools to interview two of their P6/P7 teachers; we thus planned to interview sixty teachers in total.

When an interviewer visited a school s/he filled in a brief pro-forma during introductory conversation with the headteacher. This sought basic information about the school and its catchment area and about the teachers the interviewer was going on to meet.

The number of pupils in the schools we visited ranged from 90 to 590 and averaged 300; the number of teachers varied from 5 to 22 and averaged 13. The location of the schools was described by headteachers as shown in Table 2.5. The nature of the school catchment was described by headteachers as shown in Table 2.6. Three of the schools in our sample were Roman Catholic schools; the other 27 were non-denominational.

Table 2.5: *Location of Schools*

Type of location	Number of schools
Rural/Village	3
Small town	7
Large town	6
Inner city	4
Suburban estate	4
Peripheral scheme	6
Total	30

Table 2.6: *Nature of School Catchment*

Nature of Catchment	Number of Schools
Disadvantaged	4
Mixed tending to disadvantaged	4
Mixed	12
Mixed tending to affluent	4
Affluent	6

It is not claimed that this sample of schools is representative of all the primary schools in Scotland; the schools were not chosen on criteria designed to achieve representativeness. The AAP sample of schools slightly under-represents small schools; our method of selection of both regions and schools from this sample further favours larger schools. The average size of school in our sample (300) is significantly greater than the national average (187); it equates to the average size of school in, for example, Renfrew division of Strathclyde (295). In considering the implications of our findings, we should bear in mind that small schools may well have particular difficulties. In our sample, three schools (10%) were Roman Catholic; nationally the percentage of Roman Catholic primary schools is 15%. Thus, our sample contains schools of a wide variety of types; there is a good spread in terms of size, geographical situation and socio-economic characteristics. Small schools and rural schools are under-represented; to a lesser degree, so also are Roman Catholic schools.

The order of the interview topic groups, A and B, was varied from school to school; the order of topics within A and B interviews was also varied to avoid possible sequence effects. Twenty-eight teachers discussed with us each of the three A topics (Arm, Carbon Dioxide and Mirror); 27 teachers discussed each of the three B topics (Water, Fish and Circuit).

The interviews, including time to establish rapport and to cover the necessary points in preamble, lasted an average of about 50 minutes and varied in length from 30 to 70 minutes. All the interviews were recorded on audio-tape.

Preparation of interview data for analysis

As it was not possible on cost grounds to prepare full transcripts of all 57 interviews, an alternative procedure was devised. Two interviews were first transcribed in full; from these transcripts a 'data-prep' form was drafted which it was hoped would allow us to write down data directly while listening to the tapes. The draft was tested against a further four transcripts and by listening to the six tapes of these interviews. A modified 'data-prep' form was then used for all 57 interviews.

The form had four main parts. One part was for each of the three science topics with technology extensions. The fourth part was used to record information of a general nature about teacher confidence and forms of help requested and to record verbatim quotes that we thought might be useful to illustrate points in the final report.

The main things entered on the forms were as follows.

— A judgement by the researcher of the understanding displayed by the teacher of each of the 'big science ideas' and of the ways in which that understanding changed, if at all, during the process of collaborative explanation. For each idea a symbol was used:

  + + understanding shown without any prompting or assistance

  – + understanding developed by the end of the discussion (or understanding revealed, that teacher claimed originally not to possess)

  – – no evidence of understanding of the idea, either initially or after discussion

  NE insufficient evidence for a valid inference of understanding.

  Originally we expected to make use of an additional category of judgement: + – but this was found to be necessary only under the next heading, teachers' *own* perceptions of their understanding.

— For each science idea, teachers' *own* perceptions of their understanding were coded using a similar system:

  + + 'I understood the idea at the beginning: my understanding did not change.'

  – + 'I didn't understand this – but I do now.'

  – – 'I didn't understand this – and I still don't.'

  + – 'I thought I understood this; but now I realise I didn't.'

  NE Insufficient evidence for us to know the teacher's view.

— Supplementary points concerned with understanding were noted.

— Any misunderstandings were described in detail.
— Teachers' views on the difficulties of developing the ideas in pupils were summarised.
— For each technology topic we recorded a description of
  - the general level of understanding/familiarity displayed
  - any specific misunderstandings
  - difficulties in teaching encountered or predicted.
— A summary was made of points made/reasons given in relation to level of confidence about science/technology teaching.
— Details were noted on the action requested by teachers to support their science/technology teaching.

Two researchers listened to all the tapes and conferred regularly on progress and any problematic aspects; one researcher focused on understanding of ideas in science and technology, the other focused on teacher confidence and support requested.

This procedure for the first stage of data preparation/analysis worked well, except in one regard. It was felt that the researchers' judgements on understanding could readily be supported and defended by the evidence available, but that the codings of teachers' *own* perceptions were sometimes being made with less evidence than was desirable. Teachers were pleased to recognise that their thinking was confirmed by the interviewer in his/her statement of the big ideas (see p20 (5)) and then tended to say 'I think I understood that all along really ...'; it was then difficult for the interviewer to elicit a reaction to *each* idea, rather than the ideas in general. We feel that any descriptive claims based solely on the data about teachers' perceptions of their own understanding would have relatively low validity and thus we have not made such claims in Chapter 4. Data from this phase of the interviews were, however, useful in supplying additional evidence to support the researchers' judgements on teacher understanding and how it changed.

Was the interview strategy effective?

(a) Fifty-five of the 57 teachers co-operated fully; two teachers asked us to discontinue the collaborative explanation aspect and the interviews continued as conventional discussions of the issues in science/technology teaching in primary schools.

(b) In 50 of the 55 cases, teachers were apparently relaxed and fully engaged after the first five minutes; in five cases there was an element of unease observable throughout the whole period.

(c) In about a quarter of cases teachers made unsolicited comments about how much they had enjoyed the whole process. (Rather worryingly, two teachers said their understanding had increased so much that they would now teach these topics with confidence.)

(d) A pleasing number of teachers volunteered to work with us again in Phase 3; this was at a time of intense concern about teacher workload.

(e) There were three interviewers; they were trained in the procedure and managed to follow it without difficulty. They found the method demanding and tiring – as did the teachers. Although many things were probed in depth, some opportunities for in-depth diagnosis of teachers' alternative conceptions were missed. On reflection, probably too much was attempted in the time.

In summary, with regard to our central purpose of obtaining data to describe teachers' understanding and the desire to be seen as researchers rather than testers, examiners or inspectors, the method was effective. As always, we could improve our implementation of the method given the opportunity to carry it out again.

■ Phase 3: telephone interviews

In this phase we aimed to explore the difficulties which P6 and P7 teachers faced in their routine teaching of scientific and technological topics.

At the end of January 1994 we wrote to each of the schools which had taken part in Phase 2, asking if two P6/P7 teachers would be willing to talk to us over the phone about any science and technology taught in the course of the spring term. Two discussions per teacher were envisaged, the first near the end of February, the second around Easter. Schools were sent copies of an aide-memoire (Appendix 2) on which teachers could make brief notes which would serve as a basis for the phone discussions, and a pro-forma on which to indicate which times and dates would be most suitable for telephone interviews. We stressed that teachers should not change their teaching plans in any way, as we had no wish to add to teachers' workload, and wished to get at the real situation.

The interviewees

Thirty-three teachers from 20 schools took part in the telephone interviews. All except four of these had taken part in Phase 2, and 15 had also responded to the Phase 1 questionnaire. It might be expected that the least confident teachers would be unwilling to continue co-operating with us and would find some way of dropping out of the research. However, a scrutiny of the evidence available from those teachers who had taken part in earlier phases suggests that the Phase 3 teachers were not significantly more confident overall than those in the earlier samples. We do not claim that the Phase 3 teachers are a representative sample of all Scottish primary teachers, but we have no reason to believe they are very different from the rest of the primary teacher population.

The interviews

The interviews were piloted in late February and conducted between March and June 1994. The idea of double interviews for all proved not only impractical but unnecessary, and was only put into practice with four teachers who were planning further science/technology activities beyond Easter. Conversations varied in length from five minutes to half-an-hour, but averaged 15-20 minutes. Not all teachers had made use of the aide-memoire, but the structure of the conversations generally followed that suggested by the format: a description of the lessons undertaken, the teacher's level of satisfaction, identification of any

problems encountered and their causes, and indication of any help which would have been useful. The interviewer used the same aide-memoire format to record each conversation. Completed sheets were returned by eight teachers (ranging from one to eight sheets per teacher), and these were used to supplement the interviewer's own record of the interviews.

■ Phase 4: Interviews in teacher education institutions

In this phase we sought to learn what is done in initial and in service training to help teachers develop their own understanding of science and technology. The research questions guiding this phase of our work are given on pp9–10 of Chapter 1.

There are currently five establishments in Scotland responsible for the initial training of primary teachers. Until recently these were all called colleges of education; there are now two colleges (one associated with a university and one not), two university faculties of education and one university institute of education.

We wrote to the principals/deans of the teacher education institutions outlining the purposes and design of our research, seeking their approval to approach members of their staff and asking them to identify those members it would be most fruitful to interview. In addition we sought documentation describing the relevant courses they provided. All five institutions co-operated fully.

The interviewees

Thirty members of staff of teacher education institutions were interviewed in October/November 1994. These included sixteen tutors in science, technology and primary education (with both pre-service and in-service inputs), four heads of science/technology departments, five course leaders (two for PGCE Primary and three for BEd Primary), four in-service co-ordinators and one research officer.

The interviews

The interviews were required to serve several purposes and were with people with very different types of remit.

The central purpose was to explore what is done to help teachers develop their own understanding of science and of technology. However, what is done is changing and will go on changing. We therefore had to concern ourselves with the current position, how that has recently changed, what future changes are planned and people's perceptions of the adequacy and desirability of the changes. The people we spoke to sometimes had a broad, strategic responsibility; others led or managed courses or components of courses; others were concerned with teaching inputs – but these could be within environmental studies, or science or technology and could be in initial or in-service training (or both). In addition a few people had an involvement with the production of teacher materials organised by the Scottish Consultative Council on the Curriculum.

Interviews were semi-structured; a lengthy schedule was devised and then given to the advisory committee for modification and approval. A condensed version of this is included as Appendix 3.

Interviews varied in length from 35 to 75 minutes and averaged 50 minutes.

Additional Interviews

By talking with people in teacher education institutions (and analysing the documents they produced) we could get a reasonably comprehensive picture of initial teacher training for primary school teachers; we could also get at important aspects of in-service provision. There are, however, agencies other than teacher education institutions which have significant inputs to the professional development of teachers; the most important of these are the education authorities.

Time and resources prevented us from interviewing all the appropriate people (mainly advisers) in all the education authorities in Scotland. We therefore rounded out our picture of in-service provision by talking at length with three advisers: the chief adviser (primary education) of a large authority, the adviser in science and the adviser in technology of two medium-sized authorities. The main findings of this phase of our work are described in Chapter 4.6.

3 The teachers who helped us ... 1

Characteristics of teachers in Phase 1

We approached the 119 schools already selected for the AAP Science Survey; 99 schools (83%) responded positively. Five hundred and fourteen teachers (estimated to be 93% of all P3, P4, P6, P7 teachers in those schools) completed questionnaires for us. Their characteristics were as follows:

Gender

1 – of the 514 respondents, 8% were male and 92% female. This agrees closely with the distribution by gender of all teachers in education authority primary schools in Scotland.

School role

2 – 248 people (ie 48%) were teachers of P3 and/or P4; 259 people (ie 50%) were teachers of P6 and/or P7; seven teachers taught some other class or combination of classes or did not tell us what class they taught.

3 – 18% had responsibility within the school for a particular curriculum area (or areas). Thirteen people had responsibility for science and four for technology.

Teaching experience

4 – Table 3.1 below shows how long it was since our teachers qualified and how many years of teaching experience they had. 9% of teachers had done some teaching in a secondary school. 32% had been employed for a year or more outwith teaching.

Table 3.1: *Years since qualification and years of teaching experience (N=514)*

Number of years	Number of teachers qualified this number of years	Number of teachers with this length of experience
0 – 4	66	68
5 – 11	78	111
12 – 25	285	289
25+	85	46

– 72% of teachers in the sample had been qualified for 12 years or more; 28% had been qualified for less than 12 years. 65% had been teaching for 12 years or more; 35% had taught for less than 12 years.

Qualifications

5 – 21% of the teachers had a degree qualification – either a BEd or some other degree plus PGCE. The remainder were diplomates of a college of education.

6 – Twenty people only (ie 4% of the total) had a degree containing a science subject; in 18 of these 20 cases the subject was a biological science. Only two teachers in the sample had a degree which included a pass in physical science subject.
– A further 88 teachers (ie in addition to the 20 above) had at least one Higher grade pass in a science subject. A further 90 teachers claimed at least one Ordinary Grade science pass.
– Three hundred and fourteen teachers (61%) said they had *no* science qualifications; it is possible that some of these teachers possessed Ordinary or Standard Grade passes in a science subject or subjects, but discounted these.

We should note in passing that it became compulsory for pupils in secondary schools to continue some study of science into S3 and S4 in 1988. This means that students (except mature students) obtaining BEd degrees from 1995 onwards should all have some science beyond S2; increasingly the majority of teachers entering primary schools should have at least a minimum of one Standard Grade science pass.

7 The data were analysed to explore the possibility of relationships between pairs of characteristics from: gender of teacher, stage taught, years of teaching experience and possession of a science qualification.
There were three relationships that were statistically significant:
(a) gender and stage taught – male teachers were more likely to teach at the upper stage of the primary school than the lower ($p \leq 0.01$)
(b) gender and science qualification – male teachers tended to have more science in their educational background than did female teachers ($p \leq 0.05$)
(c) years of teaching and science qualification – teachers with less experience had rather more science in their background than those with greater experience ($p \leq 0.05$).

Inservice courses attended

Fifteen percent of teachers said they had, within the previous five years, attended an inservice course of more than one day's duration concerned with the teaching of science or environmental studies. (It should be noted that this figure does not give an accurate indicator of the amount of inservice support in science received by our respondents. Some people included one-day courses; some made it clear that they were including two half-days as more than one day, whereas others may not have done; some mentioned aspects of environmental studies with no obvious relationship to science/technology.)

This question does not capture information about all the inservice provision experienced by teachers; doubtless there is much inservice that is supplied in single days. However, as many as 85% of Scottish primary teachers had no recent experience of inservice support in science/environmental studies other than that supplied in single days or less. Only 19 teachers out of 514 had taken part in an award-bearing course in the science/environmental studies area within the last five years.

It seems highly unlikely that this level of provision/uptake will be adequate to support teachers in meeting the coming challenges.

Table 3.2: *Inservice courses attended–general subject area*

	Number of courses
Environmental Studies (general)	30
Technology	21
Science	19
Information Technology	6
Total	76

Table 3.3: *Location of inservice courses attended*

	Number of courses
College of education/university	33
Teachers' centre	24
Own, or neighbouring, school	14
Unclear	5
Total	76

Table 3.4: *Length of inservice courses attended*

	Number of courses
Two days	24
Distance learning over extended period	17
Three to five days (continuous)	16
Three or more half days (or evenings)	9
Longer than one week (continuous)	4
Other, or unclear	6
Total	76

Table 3.5: *Nature of award–if any*

	No. of courses
No award	55
First level certificate course	16
Part of inservice BEd.	2
Component of higher degree	1
Unclear	2
Total	76

When we report findings based on Phase 1 data (as, for example, in Chapter 4.1 on teachers' confidence), it is reasonable to claim that the results can be generalised with a degree of confidence to the population of primary teachers as a whole. The method of sampling, the sample size, and the high response rates tend to justify this. There are two minor reservations: teachers in small schools will be under-represented (a feature of AAP sampling); headteachers will be under-represented (we asked them to pass on the questionnaires to teachers of particular classes).

The teachers in Phase 2

We interviewed teachers in 30 schools as described in Chapter 2.2. The schools were varied; there was a good spread in terms of size, geographical situation and socio-economic characteristics. Small and rural schools were somewhat under-represented; to a lesser degree, so also were Roman Catholic schools.

We had asked headteachers if we could meet two teachers of P6/P7. We actually interviewed 57 teachers. In three schools, only one teacher could be made available at the time of our visiting; a 'flu epidemic hit Scottish primary schools in November/December 1993 and caused high staff absence rates. We have no systematic information on how these teachers were selected; it became clear that some were enthusiastic volunteers, others were willing nominees, a few were reluctant conscripts. Some characteristics of the teachers interviewed are given in Table 3.6. Percentages of teachers within each category in the questionnaire survey are given for comparison.

Table 3.6: *The teachers in the Phase 2 sample (N=57)*

Characteristic		Number of teachers	Percentage of teachers	Percentage in survey sample (N=514)
Gender	Male	4	7	8
	Female	53	93	92
Teaching experience	12 years or more	39	68	72
	Less than 12 years	18	32	28
Science background	No science	38	67	61
	Some science	19	33	39

As indicated on page 34 the teachers in the *survey* sample were reasonably representative of all P3/4/6/7 teachers in Scotland. The sample of P6/P7 teachers *interviewed* have broadly similar characteristics; this sample is probably somewhat short on males (as males are more likely to teach at P6/P7 than at P3/P4); it may be that experienced teachers are slightly under-represented and that those with no science in their backgrounds are slightly over-represented. It will be shown later that those with less teaching experience tend to be more confident in teaching science and technology and that those with no science in their backgrounds tend to be less confident; it is thus unlikely that the composition of this sample results in any very significant variation from the norm, as regards confidence in science and technology.

Of the 57 teachers of P6/P7 interviewed in Phase 2, 37 had also completed Phase 1 questionnaires as P6/P7 teachers in the same school. Eighteen had either taught at some other stage in the school or had been appointed to that school at the beginning of the 1993/94 session.

Although there is no reason to believe the teachers in Phase 2 are very different from primary teachers as a whole, it is not claimed that they constitute a representative sample. Thus findings from Phase 2 should not be boldly generalised to the primary teaching population in Scotland. However, the picture of teacher

understanding of concepts in science and technology that we give in Chapter 4.2 and 4.3 is an interesting one that deserves careful consideration.

The teachers in Phase 3

The headteachers of 20 of the Phase 2 schools agreed that we could work with some of their teachers again in Phase 3; the remainder declined, the reasons given being general issues of teacher workload and the high level of staff illness at the time of our asking. Thirty-three teachers from these schools took part in Phase 3 – keeping notes for us on their actual teaching of science and technology and being interviewed by us on the telephone.

Some characteristics of the Phase 3 teachers are given in Table 3.7. Percentages of teachers within each category in the Phase 1 survey are given for comparison.

Table 3.7: *The teachers in the Phase 3 sample (N=33)*

Characteristic		Number of teachers	Percentage of teachers	Percentage in survey sample (N=514)
Gender	Male	4	12	8
	Female	29	88	92
Teaching experience	12 years or more	20	61	72
	Less than 12 years	13	39	28
Science background	No science	19	58	61
	Some science	14	42	39

The Phase 3 sample of teachers contains one more man than one might wish on a straight numerical application of the survey percentages; the sample contains rather more young or less experienced teachers than the survey sample. One might predict that this would mean the sample contains teachers somewhat more confident about teaching science and technology than the norm. We checked this for those teachers for whom we had confidence ratings from Phase 1 and found there was no statistically significant difference.

Amongst the 33 Phase 3 teachers there were four who were completely new to us; they had offered to become involved in place of a colleague, to share out the involvement. Thus 29 teachers were involved in both Phases 2 and 3; 15 teachers were involved in all three phases.

It is not claimed that the Phase 3 sample is representative of the primary teaching force as a whole. However, the teachers are sufficiently varied to shed some illumination on the difficulties actually experienced, and the successes achieved, in teaching science and technology more generally. Data from these teachers provide the main substance for Chapter 4.4 and contribute to parts of other sections in that chapter and to the discussion of issues in Chapter 6.

In this chapter we have reported on the characteristics of the teachers in a de-personalised way. In Chapter 5, we provide six profiles of teachers, pulling in information from a variety of sources.

4 What we found out ...

4.1 ... about teachers' confidence

4.2 ... about teachers' understanding of science

4.3 ... about teachers' understanding of technology

4.4 ... about classroom practice

4.5 ... about help wanted by teachers

4.6 ... about initial and inservice teacher education

4.1 ... about teachers' confidence

■ Phase 1: The questionnaire survey

A copy of the questionnaire is included as Appendix 1. An account of the survey and a summary of the questionnaire are given in Chapter 2.

The categories

In most of the closed-response items in the questionnaire the teachers had to respond by ticking one of four boxes. Teachers were given the following interpretations of the four:

Category 1: Fully confident in my knowledge and skills.

Category 2: Confident with a little guidance from others.

Category 3: I can manage but depend on advice from others.

Category 4: I need help to develop my knowledge and skills in this area.

The tables which follow give the percentage of the respondents who ticked each category/box. In addition, we have calculated for each item a 'confidence index' – given in the last column of the tables. This is an attempt to take more sensitive account of the intermediate judgements than is found by collapsing categories of response into, say, 'confident' and 'not confident', giving each category of judgement a due weighting. The percentage entered in category 1 is multiplied by 4; in category 2 by 3; in category 3 by 2 and in category 4 by 1. These four products are then added to give the confidence index. The maximum possible confidence index for each item is thus 400 and the minimum is 100. An even distribution across the four categories would give a median index of 250.

CONFIDENCE IN AREAS OF THE PRIMARY CURRICULUM

The preamble to this part was: 'Some teachers are more confident in their knowledge and teaching skills in some areas of the curriculum than others. Please give an honest estimate about how you feel in general about teaching the following ...'

Primary teachers have very much less confidence in their knowledge and skills in science, information technology and technology than they have in the traditional core subjects of English and mathematics. The percentages of teachers admitting to dependence on advice from others and to needing help in science and technology are 41% and 60% respectively, this compares with only 1% in English and mathematics. Teachers are even less confident about technology and information technology (and music) than they are about science (Table 4.1).

Some comparison is possible between the figures quoted for Scotland and those given by Bennett *et al* (1992) for England and Wales (Table 4.2). The curriculum areas, their names and the category system employed are *not* identical.

Table 4.1: *Teachers' feelings of confidence about different areas of the primary curriculum: percentages of teachers (N=514)*

Subject Rank	Subject	%				Confidence Index
		Cat 1	Cat 2	Cat 3	Cat 4	
1=	English	71	28	1	0	370
1=	Mathematics	71	28	1	0	370
3	Health Education	37	52	11	1	327
4	Social Subjects	39	50	9	2	326
5	Religious Education	33	46	16	5	307
6	Physical Education	27	51	19	3	302
7	Art	26	46	22	6	292
8	Science	12	46	25	16	252
9	Music	16	28	37	19	241
10	Information Technology	7	37	29	27	224
11	Technology	6	34	35	25	221

Fully confident – Cat 1 – Competent
Confident with a little guidance – Cat 2 – Competent with a little help
Can manage, depend on advice – Cat 3 – Relatively competent but needinservice and help
Need help to develop knowledge and skills – Cat 4 – Not competent; need substantial inservice

Table 4.2: *Teachers' feelings of confidence/competence about different areas of the primary curriculum: subject rank comparison.*

Subject Rank (Scotland 1993)	Subject	Subject Rank (England/Wales 1989)	Subject Rank (England/Wales 1991)
1=	English	1	1
1=	Mathematics	2	2
3	Health Education	–	–
4	Social Subjects	–	–
	History	3	5
	Geography	4	7
5	Religious Education	7	8
6	Physical Education	6	6
7	Art	5	4
8	Science	8	3
9	Music	9	9
10	Information Technology	–	–
11	Technology	10	10

Given the differences in curriculum terminology and category descriptions, there is a remarkable correspondence between the 1993 (Scotland) rankings and the 1989 (England and Wales) rankings (Table 4.2). Technology comes at the bottom of both lists. Science is in eighth place in both lists.

Technology is at the bottom of the rankings in England and Wales in both 1989 and 1991. The most striking difference between the two England/Wales lists is the movement of science from position 8 to position 3. The researchers attribute this mainly to the provision of resources in support of science since 1989: '...the allocation of resources, both human and material, to science teaching, together with the provisions set out in statutory orders, have been of benefit in enhancing teachers' self-perceptions of their competence to teach National Curriculum science ...' (Bennett *et al*, 1992).

CONFIDENCE IN TEACHING KEY FEATURES OF SCIENCE AND TECHNOLOGY

The preamble to this part was: 'How confident do you feel that you have the knowledge needed to help pupils develop understanding of each of the following, quoted from the *5–14 Guidelines for Environmental Studies*? Please rate them 1–4 using the same criteria as in the previous question.'

Understanding Living Things and the Processes of Life

Teachers were asked to rate their confidence with regard to six topics on which pupil study should focus; these six are within the broad attainment outcome 'Understanding Living Things and the Processes of Life' (*Guidelines* pp 16–17). Three are for stages P4 to P6 and three for stages P7 to S2. (The results are given in Table 4.3, where the categories are defined as for Table 4.1.)

In the area of biological science, primary teachers have conventionally been considered to be fairly confident, a point borne out by this evidence. Conflating responses in categories 1 and 2 we can say that about two-thirds of teachers are reasonably confident; about one-third appear to need significant amounts of advice and help.

Within this crude overall picture there is a wide variation on feelings of confidence expressed: 80% claim to be confident about simple food chains, only half that number are confident about the main distinguishing features of flowering and non-flowering plants and micro-organisms.

Care should be taken not to attach too much significance to individual items. Some of the statements are long, contain several parts and a number of examples. One might expect primary teachers, for example, to be confident in their knowledge of the main features of flowering plants – but to be hesitant about what they remember of monocotyledons and dicotyledons. If they have forgotten the main distinguishing features of viruses, perhaps they record a low confidence level for the item as a whole, although they are confident about all its other parts.

The average confidence index for the P4/P6 topics (302) is greater than that for the P7/S2 topics (262). (The stage to which items refer was ***not*** given in the questionnaire.)

Table 4.3: *Teachers' confidence on aspects of 'Living things ...': percentages of teachers (N=514)*

Stage		%				Confidence
		Cat 1	Cat 2	Cat 3	Cat 4	Index
P4/6	Simple food chains based on energy from the sun.	39	41	17	3	316
P4/6	Structure and functions of the major parts of the human body as they relate to the processes of movement (muscles, bones and joints) and nutrition (teeth and digestive system).	37	43	15	5	312
P7/S2	Structure and functions of the major parts of the body as they relate to the processes of respiration, excretion, sensitivity and reproduction.	32	39	21	9	296
P4/6	The main distinguishing features of vertebrates (fish, amphibians, reptiles, birds and mammals), major invertebrate groups (worms, molluscs, arthropods such as insects, spiders and crabs).	24	40	26	9	277
P7/S2	Adaptation to the environment over a period of time, leading to an understanding of the process of evolution and the survival or extinction of species.	21	32	33	14	260
P7/S2	The main distinguishing features of flowering (mono-cotyledons, dicotyledons) and non-flowering plants (algae, mosses, lichens, ferns, fungi, conifers) and micro-organisms (bacteria and viruses).	11	32	31	27	229
	Average – over three P4/P6 items					302
	– over three P7/S2 items					262

Understanding Energy and Forces

Teachers were asked to rate their confidence that they have the knowledge needed to help pupils in seven topics selected from the attainment outcome 'Understanding Energy and Forces'. (*Guidelines*, pp 18–19). Five are for the stages P4 to P6 and two for stages P7 to S2. (Table 4.4)

Table 4.4: *Teachers' confidence on aspects of 'Energy and Forces': percentages of teachers (N=514)*

Stage		%				Confidence
		Cat 1	Cat 2	Cat 3	Cat 4	Index
P4/6	Mirrors and reflections, including curved mirrors	15	36	34	16	252
P4/6	Sound from a variety of vibrating sources eg tuning fork, violin string, radio and TV speaker	15	32	35	18	244
P4/6	Force of gravity	13	33	33	22	239
P4/6	Construction of battery-operated circuits to operate eg bells, buzzers, lamps, warning lights.	17	29	29	25	238
P4/6	Earth's magnetic field and the compass	13	32	35	20	238
P7/S2	Renewable and non-renewable sources of energy	12	33	32	23	234
P7/S2	Potential and kinetic energy	8	21	28	43	194
	Average – over five P4/P6 items					242
	– over two P7/S2 items					214

In this area of physical science teachers' expressions of confidence in their knowledge is generally lower than in biological science. Conflating categories 1 and 2 and categories 3 and 4, less than half claim to be reasonably confident; more than half say they need significant amounts of advice and help. Compared with 'living things' there is less variation across the items in this area; with the exception of 'potential and kinetic energy', there is little difference in the responses to the items.

Again it is interesting to speculate on the way in which the inclusion of examples affects teachers' responses. Does the spelling out of examples make it easier to see what is meant to be included and thus increase one's confidence? Would some teachers have felt more confident about their knowledge of sources of sound if they only had to consider the tuning fork and violin string – and not radio and TV speakers? Does the guidance to include curved mirrors when considering reflections make people feel more or less confident?

It does seem strange that the authors of the guidelines feel the need to amplify circuits and sounds, but not force of gravity and potential and kinetic energy.

The average confidence index for the P4/P6 topics (242) is greater than that for the P7/S2 items (214).

Understanding Earth and Space

Teachers were asked to rate their confidence on six statements (three from P4/P6 and three from P7/S2) selected from those given on pp 20–21 of the Guidelines (Table 4.5). This area is also physical science; one can detect in it the topics from which chemistry, geology and astronomy might later develop. Teachers' confidence in their knowledge in this area is somewhat higher than in 'Forces and Energy' – indeed it is similar to that for the biological area 'Understanding Living Things'.

Table 4.5: *Teachers' confidence on aspects of 'Earth and Space': percentages of teachers (N=514)*

Stage		%				Confidence Index
		Cat 1	Cat 2	Cat 3	Cat 4	
P4/6	The water cycle (in simple outline) introducing water as a gas, melting, freezing, evaporation, condensation.	47	37	13	4	329
P4/6	The planets of the solar system	28	41	25	6	291
P4/6	Natural and manufactured materials and simple examples of recycling	25	43	27	6	289
P7/S2	The motions of Sun, Moon, Earth and planets and related effects, eg day/night, seasons, phases of the moon	28	39	26	6	287
P7/S2	The structure of the Earth: the Earth's crust and processes which led to the formation of main features in it, eg formation of different types of rocks, fossils.	22	33	30	15	262
P7/S2	Fossil fuels: occurrence, combustion and effects of emission of 'greenhouse gases'; methods of overcoming/avoiding atmospheric pollution; other uses (outline only).	14	34	35	17	245
	Average – over three P4/P6 items					303
	– over three P7/S2 items					265

Again, the average confidence index for the P4/P6 items is higher than that for the P7/S2 items (303 compared with 265).

About two-thirds of teachers are reasonably confident; one-third admit to needing significant amounts of advice and help. There is a wide variation in confidence in this area: over 80% are confident about having the knowledge to teach the water cycle – but less than half are confident in their knowledge of fossil fuels and the greenhouse effect.

Confidence in science knowledge for different stages

In the previous sections the science topics have been grouped by attainment outcome; they could alternatively be grouped by stage, ie whether the 'foci for study' are recommended for P4/6 or P7/S2.

Table 4.6: *Teachers' confidence on the science 'topics' by stage to which these are allocated; percentages of teachers (N=514)*

Stage		%				Confidence
		Cat 1	Cat 2	Cat 3	Cat 4	Index
P4/6	Average for 11 items	25	37	26	12	275
P7/S2	Average for 8 items	19	33	30	19	251

In the questionnaire there was no indication whether the statements quoted came from the P4/6 or P7/S2 lists in the Guidelines. It was possible, of course, for teachers to consult the Guidelines and find this out.

The figures in Table 4.6 show there is a tendency for teachers to feel more confident that they have the knowledge needed to teach the P4/P6 items. 62% could be said to be reasonably confident as against 52% for the P7/S2 items. The average confidence index for P4/P6 items is 275; for P7/S2 items it is 251. In other words, P7/S2 items are seen in some way by teachers as being more difficult; this lends some confirmation to the idea that there is progression built into the guidelines. The trend is clearly in the right direction; whether the magnitude is significant is problematic.

Understanding and using technology in society and Understanding and using the design process

In the questionnaire, seven items were included to represent these two broad attainment outcomes for Technology Guidelines (pp 48–51).

Teachers' confidence that they have the knowledge needed to develop these technology ideas in pupils is relatively low (see Table 4.7). The average confidence index is 225, ie below the median value and lower than that for the science attainment outcomes.

Again, if we conflate categories 1 and 2 and categories 3 and 4, it seems that around 60% of teachers are reasonably confident about those aspects of technology which mention people, individuals or users. However, if the focus is on control or process, the percentage who claim to be reasonably confident falls to around 20%.

Over 80% of teachers admit to needing significant amounts of advice and help to teach two of the topics suggested for P4/P6.

The technology statements are longer than the science statements; sometimes they have considerable detail in the examples supplied. There was not always room to include all the examples in the questiionnaire. The effect of this exemplification on perceptions of confidence is again unknown. It is possible that when examples are given in the science statements they make things appear more difficult, but when given in technology they help the unfamiliar seem more accessible.

Table 4.7: *Teachers' confidence on aspects of Technology: percentages of teachers (N=514)*

Stage		%				Confidence Index
		Cat 1	Cat 2	Cat 3	Cat 4	
P4/6	Simple relationships between the ways people live and the technologies they use in different communities and environments	18	46	28	8	274
P4/6	The effectiveness and drawbacks in the design of local environments for different groups of users, eg the supermarket for someone in a wheelchair	18	42	29	10	266
P7/S2	Ways in which individuals can use technology to change their own environment and lifestyle	15	41	33	12	261
P7/S2	Ways in which energy is converted and materials can change state, eg burning fossil fuels to create electricity	14	30	36	19	237
P4/6	Simple relationships between the way people control their movements and the way control technology helps us to produce automated systems to control our environment	4	22	38	36	194
P4/6	The different stages of the design process and strategies they can use within these stages	3	17	31	50	175
P4/6	How control technology can be used for specific purposes in different situations, eg computer interface to control lights and meters	3	13	33	50	167
	Average – over five P4/P6 items					215
	– over two P7/S2 items					249

On this sample of technology items, teachers seem less confident about the P4/P6 statements than the P7/S2 ones.

Confidence in science process strands

The *Environmental Studies Guidelines* describe four strands (in addition to knowledge and understanding); these are planning, collecting evidence, recording and presenting, interpreting and evaluating. The questionnaire presented ten statements selected from the appropriate pages of the guidelines (pp22–29) and asked teachers to rate how confident they felt in helping pupils to do each of these things (Table 4.8).

Table 4.8: *Teachers' confidence about Science Processes: percentages of teachers (N=514)*

	%				Confidence
	Cat 1	Cat 2	Cat 3	Cat 4	Index
Observe events, noticing sequences and changes	37	45	14	3	314
Estimate, measure and draw accurately, selecting appropriate units and measuring devices	36	40	19	6	308
Identify relevant questions to investigate	26	46	21	6	290
With guidance from the teacher, recognise reliable evidence	25	43	26	6	287
Propose methods and categories for recording and reporting findings and outcomes of enquiries	25	44	22	8	284
Record evidence in a variety of appropriate ways ...; writing organised reports	25	39	26	10	279
Make predictions using knowledge and information gained in several different contexts (eg about the effects of effluent on life in rivers)	19	40	32	9	269
Decide on appropriate strategies, procedures ... ... justifying choices and monitoring for possible unfairness	19	42	28	10	268
Draw conclusions and justify them with reference to evidence (eg about conditions necessary for photosynthesis)	21	38	28	13	267
Make and test hypothesis eg about the effect of the removal of a link in a food chain	15	36	35	14	252
	Average – over 10 items				282

Teachers claim a confidence about developing science processes in their pupils roughly similar to confidence in their knowledge of biological topics and earth/space. Again, if we conflate categories 1 and 2 and categories 3 and 4, about two-thirds of teachers feel they can cope with no more than minimal support; about one-third need significant amounts of advice and help.

The variation in confidence is substantial: over 80% are reasonably confident about observation; only half are similarly confident about making and testing hypotheses. It is not easy to see any pattern in this variation. One might argue that observation, estimation, measuring and recording are processes that occupy a significant place in disciplines other than science and that teachers' confidence in other areas of the curriculum positively influences their confidence in those aspects of science. Concluding, predicting and hypothesising may perhaps be

seen as more science-specific – or more directly dependent on possession of a well-developed science knowledge base and thus confidence is rather lower. Further evidence is needed to take this interpretation forward.

It should be noted that some of the items are more focused, or homogeneous, than others. For example the first item is only observation, whereas the second includes estimation, measuring, drawing, selecting units and selecting measuring devices. It is unclear how a teacher who was confident about drawing but lacking confidence about measuring devices would have responded to such an item.

It is also worth noting that when an item includes an example this might make the process seem easier or more difficult. One might, for example, initially feel confident about drawing conclusions and then realise one knew little about the conditions necessary for photosynthesis.

For these reasons it would be sensible to avoid drawing fine distinctions amongst the confidence levels apparently expressed for different processes.

Summary Confidence Ratings for Science and Technology

The average percentages in each of the four categories for the three attainment outcomes of science, for technology and for science processes are given below in Table 4.9.

Table 4.9: *Summary of percentage responses for science and technology across categories (N=514)*

	%				
	Cat 1	**Cat 2**	**Cat 3**	**Cat 4**	**Average Confidence Index**
Understanding Living Things and the Processes of Life	27	38	24	11	282
Understanding Energy and Forces	13	31	32	24	234
Understanding Earth and Space	27	38	26	9	284
Technology in Society and the Design Process	11	30	33	26	225
Science Processes	25	43	25	8	282

Teachers appear to be more confident about their knowledge of biological topics and earth/space and about their ability to develop science processes in pupils; they are less confident about energy/forces and technology.

One-third of teachers say that they need a significant amount of advice or help with living things, earth/space and science processes; well over half say they need such advice and help with energy/forces and technology.

Professional Skills in Teaching Science and Technology

Previous sections of the questionnaire were based on items selected from the Guidelines; this section (No 10, page 5 in Appendix 1) featured skills of science and technology judged by the research team to be important ones. Teachers were asked to estimate how difficult they found the deployment of these teaching skills in science and technology teaching.

Category 1 = Not at all difficult
Category 2 = Sometimes a little difficult
Category 3 = Usually quite difficult
Category 4 = Very difficult.

Table 4.10 *Teachers' estimates of difficulty of certain skills in teaching science and technology: percentages of teachers (N=514)*

	Cat 1	Cat 2	Cat 3	Cat 4	Difficulty Index
Introducing a new topic	58	39	3	0	145
Ensuring the equal interest and participation of boys and girls	50	39	10	1	162
Explaining ideas to pupils	41	54	5	1	168
Responding to pupils' ideas about content	41	53	6	1	169
Using questioning skills to stimulate pupils' thinking	39	50	10	1	173
Matching activities to pupils' development and needs	23	55	18	3	199
Deciding concepts to be developed in an activity	17	64	16	3	205
Deciding process skills to be developed in an activity	17	59	20	4	211
Organising and supporting practical work	17	57	23	3	212
Record keeping	15	43	32	10	237
Obtaining and maintaining equipment	11	43	36	10	245
Continuous (diagnostic) assessment in relation to concept development	8	45	35	12	251
Continuous (diagnostic) assessment in relation to process skills	7	46	36	11	251

Note: Items are listed in order of increasing difficulty. The 'Difficulty Index' is calculated in a similar way to the 'Confidence Index'. The maximum possible difficulty index is 400; the minimum is 100.

Only the last two items have a difficulty index above the median value of 250. About half of our teachers find diagnostic assessment usually quite, or very, difficult. On all the other items the balance of response is on the 'a little difficult – or not at all difficult' side.

On the other hand, category 2 means that the skill is difficult (on occasion); so we find that, with the exception of introducing the topic, at least half of all primary teachers – and sometimes as many as 93% – find aspects of science/technology difficult, to some degree.

Some of these results need more cautious interpretation than others. For example, 'matching activities to pupils' development and needs' is extremely demanding if it means that each activity is carefully matched to the developmental stage and needs of each pupil (so-called 'micro-matching'); it is much less demanding if it means a broadly appropriate response to some perceived general

level/needs ('macro-matching'). Only 3% of teachers thought that matching was ***very*** difficult; perhaps the majority had 'macro-matching' in mind?

These figures give little support to the hypothesis that teachers believe science/technology teaching difficult because they themselves find the content of science/technology difficult. The teachers' own understanding of concepts in science and technology is perhaps most relevant to 'explaining ideas to pupils' and 'responding to pupils' ideas about content' – and yet over 90% of teachers say they find little difficulty with these.

The only relatively safe conclusion in this section seems to be that although Scottish primary teachers have no problem in admitting to a lack of confidence with some aspects of science and technology – and agreeing they need advice and help with the content – nevertheless they are quite buoyantly confident about their ability to exercise most of the teaching skills central to effective science/technology teaching.

Whether this confidence is well-founded or misplaced cannot be answered by questionnaire evidence.

QUESTIONNAIRE RESPONSES: ANALYSIS BY SUB-GROUPS

Further statistical analysis of questionnaire responses was carried out to see if there were any significant differences in the patterns of response to the structured questions from different sub-groups within the total group of primary teachers who responded. We also ran a 'women-only' analysis to detect whether the characteristics of the small number of male teachers might be obscuring differences amongst the females with regard to stage taught, length of experience and amount of science in background.

In what follows, all differences quoted are significant at the 5% level at least. ($p \leq 0.05$)

Gender of teacher

In considering these findings it should be remembered that male teachers are likely to have more science in their eductional background than female teachers.

1 Male teachers were more confident than female teachers in five of the eleven areas of the primary curriculum: science, social subjects, technology, information technology, and physical education. In the other six areas there was no significant difference between men and women, in other words there was no area of the curriculum about which female teachers were more confident.

2 Of the nineteen items relating to confidence about possession of necessary science knowledge within question 8, male teachers were more confident about seventeen of them. In the remaining two (the main distinguishing features of vertebrates etc. and the main distinguishing features of flowering and non-flowering plants ...) there was no significant difference. There was no item in which women were more confident.

3 Male teachers were more confident about six of the seven knowledge for technology items. In one there was no significant difference (Effectiveness and drawbacks in the design of local environments ...).

4 Male teachers were more confident in six of the ten items about helping pupils develop process skills in science (question 9 of the questionnaire). There was no significant difference for four items (identify relevant questions, decide on appropriate strategies, propose methods for recording/reporting findings, observe events ...). In no item were female teachers more confident.

5 In the thirteen general professional skills for teaching science/technology (question 10) in only one was there a significant difference: men apparently found it easier to explain ideas to pupils.

Stage taught

In considering these findings it is worthwhile noting that male teachers are much more likely to teach at the P6/P7 stage than at the P3/P4 stage. Of the female teachers in the sample 48% taught P6/P7 and 52% taught P3/P4; of the male teachers 81% taught P6/P7 and 19% taught P3/P4. This difference is statistically highly significant.

1 Teachers of P3/P4 were more confident about their knowledge and teaching skills in music, than were P6/P7 teachers. P6/P7 teachers were more confident about the social subjects than were P3/P4 teachers. There were no other significant differences in this section.

2 P6/P7 teachers were more confident than P3/P4 teachers about possession of necessary knowledge in five of the nineteen science items (question 8). These were circuits, renewable and non-renewable energy sources, Earth's magnetic field, natural/manufactured materials and fossil fuels.

3 P6/P7 teachers as a whole were more confident than P3/P4 teachers in four of the seven technology items; P6/P7 women teachers were more confident than P3/P4 women teachers on only two of these seven items.

4 P6/P7 teachers were more confident about helping pupils with two of the ten science process items (recording/reporting and estimate/measure ...).

5 P6/P7 teachers found it more difficult to ensure equal participation of girls and boys and to introduce a new topic.

Length of time since qualification

It should be remembered that more recently qualified teachers tend to have more science in their educational background than teachers who have been qualified for longer.

1 A comparison was carried out between those who had qualified less than 12 years previously and those who had been qualified for 12 or more years. A similar comparison was made between those who had less than 12 years teaching experience and those who had 12 or more years of experience. There were minor difference only in the results of these two analyses. The following account is based on the former analysis.

2 Those who had been qualified longer were more confident in their knowledge and teaching skills for English, mathematics and religious education; the more recently qualified were more confident about teaching science and technology.

3 More recently qualified teachers were more confident, overall, on ten of the nineteen science items; more recently qualified *women* were more confident on eight such items. There were no items on which the longer qualified were more confident.

4 The more recently qualified were more confident on nine out of the ten science process items; the only exception (no significant difference) was estimate/measure/draw.

5 The more recently qualified found two of the thirteen general skills easier than did the longer qualified: these were deciding the concepts to be developed in an activity and the process skills to be developed in an activity (the first two items in question 10).

Amount of science in background

1 Two analyses were carried out. The first involved a comparison of those teachers who had 'no science' qualifications against those who had 'some science'; 'some science' was interpreted as possessing at least one SCE Ordinary Grade in a science subject. The second analysis was of those who had 'a lot of science' against those who had 'a little or no science'; 'a lot of science' was taken as applying to those who had at least one Higher-grade pass in a science subject. These two analyses produced almost identical results. The following account is based on the some science/no science analysis.

2 Those teachers who had some science in their educational background were more confident about teaching science, technology and health education. There were no other significant differences.

3 Teachers who had some science in their background were more confident about all of the knowledge items for both science and technology (the 26 items in question 8). Women teachers with some science were more confident about 25 of these 26 items.

4 Teachers with some science were more confident on seven of the ten process items (question 9). Women teachers were more confident on six of these. There was no significant difference between the some science/no science teachers on three items: identifying relevant questions to investigate, deciding on appropriate strategies ... and estimate/measure/draw ...

5 Amongst teachers as a whole, in only two of the thirteen professional skills for teaching science/technology was there any significant difference: teachers with some science found it easier, they said, to respond to pupils' questions about content and to ensure the equal interest and participation of girls and boys. Amongst women teachers only the first of these was significant, ie the possession of a science background made no difference to women teachers' view of the difficulty/ease of ensuring the equal interest and participation of girls and boys.

Flagging-up some issues

It has to be stressed that throughout this section we have been reporting teachers' responses about their confidence in their own knowledge and teaching skills.

All of the following are possible:

- the confidence that teachers *actually* feel may be more or less than they say they feel
- teachers may have low confidence in their science understanding when that understanding is actually good – their low confidence may be unjustified

- teachers may have considerable confidence in their understanding when that understanding is actually poor – their high confidence may be misplaced
- the relationship between confidence and classroom competence is not a simple one; some of those with little confidence may make more effort to prepare their teaching effectively, and some of those with high confidence may see little need for time-consuming preparation.

Science background seems to give teachers more confidence in the parts of their teaching which relate to science *content*, but has less influence on other aspects. Length of service tends to be associated with a lack of confidence in the aspects related to science content; there is little association with other aspects. It seems we are dealing with confidence in at least two somewhat independent factors, one related to subject matter knowledge and one not. These are some of the issues taken up in Chapter 6.

■ Teachers' confidence – data from interviews

Since a substantial part of the Phase 1 questionnaire had been about teachers' confidence in teaching science and technology and since the level of confidence had been revealed to be much less than in almost all other curriculum areas, we decided not to ask directly about their confidence in Phases 2 and 3. We anticipated that at least some of the teachers might find the interviews a little anxiety-provoking (particularly in Phase 2) and did not wish to increase any anxiety; however, we also expected teachers unprompted to say things about their confidence, and perhaps to illumine something about the causes of their generally low confidence. Most teachers did indeed say such things and interviewers tried to probe with due sensitivity.

The influences on teachers' confidence tended to come from the following five areas:

- their background in science/technology – school and personal experience
- the nature of the initial and inservice training experienced
- their perceptions of their widening role and of curriculum overload
- the support available to face the practicalities of science and technology teaching
- their view of their general professional capability.

Science background

Seventeen teachers made it clear that their negative experience or lack of experience of science at school had influenced their attitude and confidence as adults. Some were particularly forthright.

> *I can't stand science. I hated it at school and haven't seen anything to make me change my mind since.*

> *I've never done experiments in my life, or ever talked a lot about science before. You're really talking to the biggest lulu about science.*

> *I was hopeless at physics. I burned my physics jotter at the end of second year, because we hated it. I'm hopeless, I don't understand it, it's like I've got a real mental block. I can learn it, I even got good marks at college, but it was only pure memory, never understanding.*

Another teacher also spoke of having 'a block, a real block, in fact a fear of it, so it would be difficult for me to teach'; and another admitted that 'the very word science makes my heart sink, and probably has done all my life'. Four other teachers spoke of being 'definitely not scientific-minded', of scientific understanding (in particular physics) not coming 'naturally' to them.

Inadequacy due to a lack of background specifically in technology was mentioned by another four teachers, one of whom saw this gap in understanding as specific to her generation.

> *I was a 60s' baby, and I just missed calculators, I just missed computers, and then I just missed Standard Grade. People my age haven't been adequately educated for the world we live in now.*

For several teachers, however, the lack of science qualifications had not stopped them developing an interest in the field, and this personal enthusiasm gave them some confidence to teach it.

> *I think if you're interested in something, then you'll feel confident - you don't need to know everything about it.*

Indeed a few teachers saw their lack of scientific background as an asset: one teacher who had attended a girls' school and 'therefore' not done any physical science had developed a compensatory curiosity in the subject; another considered that her own inexpert curiosity and drive to discover put her on a par with the children she hoped to motivate.

Three teachers considered that their enjoyment of science since childhood had given them confidence to tackle it in the classroom: 'At school I liked it, I used to find it exciting, and I feel the children do too'. One of these teachers was certain that her colleagues' general lack of confidence in science was attributable to their lack of background knowledge.

> *They are not comfortable with the science themselves, especially the explanation of scientific principles. How many primary teachers have done science at Higher level? In other areas of the curriculum, we know we are articulate and we feel confident, we know how to do the sums, we've passed our maths - 'but don't ask me about science, I don't know anything about that.'*

There seemed to be a general acceptance that confidence in tackling science teaching in primary school correlated positively with both the quantity of science done in secondary school and the pleasure derived from it. However, one teacher holding three Higher science passes and also a pass in a University science course distinguished between having the confidence to tackle the teaching and finding it easy to teach effectively; there was a difference between understanding the subject yourself and having the ability to make it easily understood by pupils; this teacher was confident about science teaching, but still found it 'problematic'.

Initial and inservice training

If their school experience had not provided teachers with confidence about teaching science, perhaps their initial training as teachers had? Thirteen teachers said (unprompted) that their initial training had *not* given them confidence.

> *I think this lack of confidence is general among primary teachers; we have not been trained. It depends on the life experience we have ourselves as to how much confidence we have to tackle this.*
>
> *I'm trying to have some expertise in science, but I don't really have it to start with. All the new things we are supposed to be doing in the primary school – I wasn't trained to do this; 27 years ago this wasn't on.*
>
> *My training never prepared me for anything of this nature.*
>
> *Nobody's ever taught me how to teach science … . What I'm saying is: if people have not been trained in science, how on earth can they teach it?*

Some teachers felt their initial training had been of no help, either because it had included no science or technology or an insufficient amount to help cope with present demands. One more experienced teacher complained that her course had only covered concepts too basic to be of use in upper school and had not addressed the pedagogy of primary science. A more recent trainee had also found too much concentration on scientific content knowledge and not enough methodology, although she had found the technology component more usefully geared towards classroom teaching. Another acknowledged her training had been of some help ('we did have labs and it was useful'), but added that it had nevertheless failed to develop her understanding by assuming too much background knowledge. Three of the four most recent graduates were critical: their scientific understanding had not been advanced; the component had been 'terrible', 'very very short', with methodology taught but not illustrated; for one, the technology component had been so specific that two or three years later she could not apply it to other contexts. In all, only three teachers gave unsolicited praise to their initial training for giving them the confidence to embark on the teaching of science and technology. Interestingly, two of these three had attended the same college.

Twelve teachers commented on their own experience of inservice training, in relation to confidence. Half of these spoke of positive effects. One teacher had been given responsibility for technology in her school after attending a two-day course. (In Phase 1 she rated her confidence much higher in technology than in science.) Five other teachers praised recent courses they had attended for giving them 'hands-on' experience which had boosted their confidence (one teacher noted appreciatively that she had been 'allowed to fool around with tools and materials'). In two cases the inservice had given teachers enough confidence to tackle the science and technology activities which they reported to us in Phase 3.

Those who were negative in their reaction said that the courses were too few or too short really to engender confidence: they were too theoretical and not sufficiently 'hands-on'; they failed, it was said, to take account of the 'real' context in which teachers worked.

The widening role and curriculum overload

Regularly, when referring to feelings of a lack of confidence about science and technology teaching, teachers spoke of the extent to which their remit had been extended already and the load of curriculum innovation they felt they had already shouldered. Science and technology were perceived by some as being the last straw which might break their confidence in their ability to cope. Twenty-two teachers spoke to us about this – many at length.

> *I panic, I just panic. There's so many things coming in. I mean, when I was at school, there was no such thing as technology. All these things are rushing ahead and you really don't have the time to find out enough about them, especially if your education wasn't of a sciency type. It's just that I think the world is changing so quickly.*

The 'generation gap' was noted by another teacher, who welcomed her pupils' awareness of green issues but hinted at the threat this could pose to her as a teacher.

> *It's one thing most children get passionate about. They've got more understanding than people of my generation, and although I'm quite interested, they actually know more than me. If you do something like this [greenhouse gases], they will actually carry it further than the teacher might have decided she wanted to go.*

It was inevitable, thought five teachers, that science and technology would get sidetracked by the 'basics' of language and mathematics.

> *I think science is very important, because I enjoy science, but I find that there is so much else, and I know this is wrong, but these sort of things tend to be 'I'll do that if I can get round to it', because parents don't want to know if their children can make a circuit, but they do want to know if they can read or if they can work out a percentage. I'm not saying it's right, but that's the hard fact.*

This teacher seemed to have no lack of confidence, but it was clear that with some teachers who did not feel confident in teaching science, the pressures of a broad curriculum served to reinforce their anxiety and perhaps even provided justification for avoiding this area of the curriculum. One teacher who admitted to sometimes feeling inadequate because of the expectation that she should have 'so much expertise in so many fields', remarked:

> *There's so much to do in the primary curriculum, you can't waste time. There's a lot of time spent on something, looking it all up, that I could have spent better helping somebody to read or helping somebody with his number. I can't afford to lose all this time over something that's just a waste.*

She also complained of the amount of time needed to prepare and set up science activities and of the uncertainty which she often felt as to the effectiveness and appropriateness of her science teaching. Another teacher was more explicit about her greater need to research and prepare science than other areas of teaching because of her lack of confidence 'in all the ins and outs'; time for such research was not always available, however, 'and I think that's when the problem arises'. It was all a matter of confidence, she said, 'confidence that you know what you're teaching'. And another expressed the combination of lack of confidence, lack of background knowledge and lack of time which limited her ambitions:

> *Time is our biggest problem, especially in science. I mean, I'm a coward – I do science, but very simple science that I can get experiments for, that I tried out at home and they work. But I don't do enough of it – I don't have enough knowledge and I panic and think 'Is this the right thing to be doing?'*

Some teachers felt strongly that in view of all the pressures it was important to resist feelings of inadequacy. As one said, within the severe limitations of time, 'I do what I can'. Since there is so much to teach and not enough time to cover everything, it seems a reasonable strategy for teachers to stick to areas of science and technology in which they feel more confident. As two teachers explained:

> *We've got to say 'Look, I'm working with a terribly overloaded curriculum, I am managing adequately with this and this and this', in case we feel terribly inadequate. I think we've got to safeguard ourselves from that. The fact is that we all make the contribution we can to the sciences, we do Ginn science to the best of our ability, and I carefully select what I feel comfortable in doing.*

> *I just feel I wouldn't be the right person to teach them about mirrors. We've all got different skills, so I would rather leave it for somebody else. There are plenty other topics you can do. We're limited, we can only do one science-based topic per year, so better do something that you're confident with.*

For one teacher this meant total avoidance of physics, in the knowledge that a school colleague whose father was a physics professor would cover a lot in that area, 'so maybe ... – they're getting it in that class, so we don't feel they lose out'.

This understandable tendency for teachers to 'stick to what you know', evidenced too in Phase 3 (though by no means universally), is quite severely challenged by the breadth of science and technology prescribed by the 5–14 Environmental Studies guidelines. Not surprisingly, several teachers felt intimidated by the document. With some teachers this related to an overall anxiety about 5–14 as a whole.

> *The guidelines just make you feel inadequate. You think 'I'm not doing everything I'm supposed to do', and that's in science, and then in technology as well, and problem-solving, and language and maths, and you just feel 'How can I fit it all in?'*

> *With all the 5–14 documents, unless you're a specialist in that particular area, it needs to be translated into what I am actually going to do with the children. We just don't know what we would do with the children to achieve a strand.*

Eight teachers had found the environmental studies document particularly daunting.

> *People are saying 'Here's what you have to do', and I know that I can't do it, because I would have to go back to basics myself to teach the environmental studies document.*

> *I feel I can tackle all the areas in that document except technology and IT. I have so little experience and background, I don't feel equipped to teach them, I don't feel confident about teaching them, I don't feel I have the resources or the training to teach them.*

As well as taking no account of the time available to teachers in the classroom, complained one, the document was neither teacher-friendly nor child-friendly, in

the depth of scientific understanding it demanded and the mystifying language in which it was couched. Jargon was a particular bugbear: it was all 'gobbledygook', said one, while her colleague suggested that the language of the document made its actual recommendations more intimidating than they really were:

> *Probably a lot of the things that you do are within the guidelines, but it makes it sound as if 'That's beyond me, I can't do it'.*

Two teachers made the complaint specifically in relation to the technology component of the guidelines ('jargon for jargon's sake', commented one). The effect of such a document on teachers whose confidence was already low was expressed by one interviewee.

> *The impression I get is that a lot of primary teachers are very wary about teaching science and feel that they don't have the necessary skills needed to do that, and looking at the 5–14 Programme and some of the language used there would possibly undermine their own...– competence isn't the word, but their own confidence about teaching the subject.*

Indeed one teacher who found the document 'very off-putting' told us that in the past she had covered much more science than she would now, and longed for the graded science scheme which the school had discarded.

Of the 18 teachers who commented on the guidelines, only one had received a boost from them; looking through the document she had realised that she did actually cover much of the science component 'without consciously planning it in under the title of science'.

Support to face the practicalities

In some cases teachers' confidence was related to how they viewed the availability of good quality support.

One teacher welcomed the availability of television series, because they could provide the children with demonstrations and explanations, 'which is exactly what I'm afraid of doing'. (In Phase 3, three teachers also used television programmes as the basis for their activities.) Another teacher, who covered only what science she felt confident in and taught it through books and project packs ('I don't stand and spout to them, we do it from books.') found no lack of printed materials available. Another stated that she had no problem obtaining reference books or videos from libraries or the teacher resource centre, but in Phase 3 complained of the time taken up selecting activities from widely disparate sources and collecting materials not available in school. A fourth teacher acknowledged the helpfulness of a good science resource area and of staff teamwork (the upper-stage teachers in her school worked as a department, thus facilitating planning, preparation and resourcing), but she nevertheless worried about her lack of background knowledge and wished for somebody who might tell her 'if I am doing it properly'. This feeling of isolation and the absence of advice and encouragement was echoed by four other teachers.

In the course of their interview ten teachers (two of them referring specifically to technology) complained of a dearth of materials, or the unsatisfactory nature of the materials available (eg not sufficiently pitched at the non-scientific teacher),

and the demand for more and better resources was a frequent one both in survey and interviews. Some teachers however felt that lack of resources was not in itself a problem. One complained that there simply wasn't the time to become acquainted with all the resources which *were* available and another that it was difficult 'finding the time to make use of the resources'.

One teacher suggested that for someone lacking in confidence, good resources could be intimidating; headteachers would happily buy resources if staff had the ability to use them, but 'I feel a lot of fear has to be taken out of it'. In her view, it was the practical difficulties associated with teaching science (finding resources, setting up equipment, managing groups on practical tasks) which made it so daunting, and demanded extra determination and confidence on the part of teachers. She herself had 'done science and *talked* about it, or done very simple activities', but shied away from practical science with the upper stages.

> *Because of the practical difficulties, you've got to be geared up, to be very confident that 'I'm going to do this', or it's very easy to know at the back of your mind that you* ***should*** *be doing it, but just letting it go and not touching it.*

In her interview she had discussed light and mirrors, and she explained the implications of teaching such a topic.

> *If I decided I was going to do a project on light, I'd have to be very confident I was going to do that project. I'd have to do a lot of work and organisation to get all the resources together, and I imagine it would not be easy. And if you did manage to get all these resources together, you'd feel pressure on you to really produce something and do a really good project.*

Although teachers did not always relate the practical implications of teaching science or technology so explicitly to their own confidence, 21 did mention this aspect as a very real disincentive. Three-quarters of these found equipment particularly problematic: good equipment was not easily obtainable, usually had to be tested at home beforehand, and setting up experiments was inordinately time-consuming. As one explained:

> *If I'm going to do experiments, I've to run about B&Q, get bits of this and that, run over to the High School to see if they've got certain things that I need. (Although we order science equipment, there's* never *enough equipment). Whereas in secondary they've got a technician who gets it all laid out, I've to spend my lunch time flying about making sure I've got everything. We have to prepare it all ourselves and it takes time, whereas it's only one small part of our whole job. It becomes such a hassle that it puts you against it before even starting it. I have to be confident I have everything – and that it works.*

One teacher complained that her classroom had no running water and that the radiators were the only heating equipment available to her, contrasting this with facilities in the secondary sector. For another teacher the lack of equipment meant that her teaching depended overmuch on work cards (although there is equally a suggestion that unless the equipment was uncomplicated she would lack the confidence to use it):

*This is where I feel my science falls down so badly, because I haven't got enough visual aids or small models to really **show** them what's happening. If we had lots of simple materials... I do most of it through task cards. We just don't have these materials, and because I don't feel confident enough, I wouldn't spend part of my class budget buying batteries etc, because I'm not in full knowledge of what I'm doing with this.*

Unsuccessful experiments were a particular phobia of several teachers. That such 'soul-destroying' occurrences might well be an integral part of scientific discovery and a valuable learning opportunity was not entirely lost on them, but would seem to be of small comfort to a teacher lacking in confidence and faced with a barrage of disappointed little faces:

Then there's the confidence in tackling an experiment, because it might not work, and they're all sitting there waiting for it to work ... and they get quite upset if it doesn't work the way it said in the book. In language, say, we have the experience of knowing everybody's different, but if you're not confident in tackling science we seem to think it should work out correctly, and they think you've done it wrong if it doesn't, and again because of your own lack of confidence you're not confident that you have done it right, and you get these accusing eyes.

Although teachers repeatedly testified to the children's enjoyment of practical experiments, these nevertheless constitute the 'wildcard' of science teaching in the classroom and as such are a worry to less confident teachers. As the last interviewee put it: 'you can't control it, and you don't always get a good result'.

Another teacher used the word control: 'perhaps liking to feel in control and have the answers is part of the make-up of the Scottish primary teacher'. This word may provide the key to this section. We began by saying the confidence was related to how teachers viewed the availability of support. Perhaps teachers' fear is that in the midst of the practicalities of science and technology teaching things will go out of control – equipment may not work, pupil materials may not be adequate, pupils may ask awkward questions; if you fear a loss of control, you need to feel that reliable support is at hand.

General professional capability

We begin with four quotations.

I was hopeless at physics... I'm hopeless, I don't understand it...it's like I've got a real mental block.

I have done quite a lot of science, but I don't know a lot, I'm not knowledgeable about it. When I'm doing it I've got to go by the book.

*I don't know things myself, but that doesn't stop me teaching it: I **have** done conservation and pollution and I **have** done energy and whatever.*

We're limited, we can only do one science-based topic per year, so better do something that you're confident with.

In isolating factors which influence teachers' feelings of confidence, we must be careful not to oversimplify. What do the above statements, for example, each reveal about the speaker's confidence or lack of it? They were all in fact spoken by the same teacher (a female teacher of very few year's experience with a school

qualification in biology), and serve as an example of the sometimes contradictory expressions of confidence which we encountered in our interviews: the teacher who would acknowledge her limitations and even reveal signs of anxiety in aspects (or the generality) of science and/or technology, but would equally display what we might call a professional confidence in the science and technology she would tackle in the classroom. This was a confidence obviously born of experience, in some cases precisely the experience of having already taught a particular topic: as one put it, 'once you've done it, you're more confident'. Four teachers expressed such confidence in the topics they discussed with the interviewer, including one who although having no science qualifications and knowing her science knowledge was limited felt no trepidation 'because my lessons are well-prepared, and teachers are used to taking their knowledge from books'. (As we shall see, however, the nub of the problem for some teachers was the perception that science could not simply be taken from books.) A fifth teacher, who admitted she had to force herself to cover science because it 'doesn't come naturally to me' nevertheless derived some confidence from realising how much she did manage to teach in the classroom.

> *It's amazing how much you know, 'cause I didn't think I knew anything about science really, but if you think about it in terms of the classroom and you say 'Och aye, I did the water cycle, oh yes and I did this, and I did a bit about oil and the energy', so when you put it together you **do** do a lot, you know a lot more than you first think you would.*

As good an example as any of the scientifically unconfident but capable teacher, she admitted that science and technology worried her more than other areas because she felt the children might know more than she did, and that 'you tend to stick to what you know'. That said, however, she embarked on an ambitious series of lessons on propulsion and submarines to link into the term's World War II theme. She was satisfied overall with what had been achieved but regretted that she lacked the necessary understanding to address all the children's problems and advance their learning.

Some teachers were clear that they had to feel they were ahead of the children. One teacher who was satisfied that the topics of Earth and Water were 'pretty straightforward' as she was 'at least half-a-dozen jumps ahead of them' explained:

> *I've got to be two jumps ahead of the children cognitively and feel equipped and competent in assisting them with their activities. They've got to think that the teacher knows better and knows all of it.*

While many teachers did not agree that they had to pretend omniscience, 18 teachers clearly felt it important that they achieve a comfortable level of understanding before tackling a topic with their class. As explained or implied by some, this level need in no way be that of a specialist but a sufficient level of understanding to allow the teacher to bring her pedagogical skills to bear with maximum effect.

For some the need for sufficient understanding was a cause of anxiety (for example the teacher who always felt 'two steps behind the children'), but for others 'the whole paranoid bit' of reading up and researching, while demanding in terms of time, was accepted as part of the job. One teacher who admitted to

being 'very nervous', 'really not confident' about physics, nevertheless covered a new science and technology topic every year, and did not worry overmuch about her own level of knowledge.

> *A lot of primary teachers are scared of science. I'm not, I see it as my job. You can't go too long without doing any science, I think you really have to try and slip it in. ... I don't feel we have to know everything, I think a lot of the time we're learning alongside the children. I ask them for* ***their*** *opinions more often than not.*

Several other teachers stressed that there was no need to 'pretend to be a know-all', but equally not a few teachers dreaded the experience of being stumped by their pupils' questions. Presumably teachers do not expect to have an answer to every question a child might put to them, and as we have seen, some teachers had no compunction about admitting they did not know. Why were some teachers, then, so worried about questioning in the areas of science and technology? One teacher, who tended to 'steer a bit away from it in quite a lot of the topics' because she lacked 'the knowledge or anyone at hand who can explain where I fell short', explained:

> *In other areas, with a difficult question I always have some source and I can tell a child 'Give me a few minutes or till tomorrow', and I can come up with that answer, but in science I genuinely cannot say that.*

Another teacher, herself very confident in these areas, sympathised; questions *were* more difficult to answer in science and answers less easily looked up:

> *With history and geography you can make a literal translation, you can go back to a book and lift it out – the idea of the Alps will not change. But pupils ask you 'Why?' and you cannot just go straight to a book and look it up. Science may be about documented fact, but the ideas of science have to be applied to a variety of situations.*

There was clearly more to teachers' concern than merely saving face in front of pupils. In this area, the inability to answer reinforced some teachers' lack of confidence:

> *When children are very keen and interested and start to ask you very detailed questions, you feel very inadequate if you cannot answer. Older children you can encourage to look for themselves, but there's still the feeling: 'Ughhh, I don't know this', and then you feel 'What am I doing here teaching something to pupils I don't understand myself?'*

We have identified teachers whose recognition of their own general professional ability means that they can approach the teaching of science and technology with a degree of confidence; they know that they teach other subjects well and they anticipate that even if problems arise they will have the skills to cope with them. However, there is another sense in which these teachers lack confidence. They judge themselves to be lacking in conceptual understanding in science and technology and as a result they are unsure that they can effectively develop their pupils' learning. They have confidence that they can cope; they are not confident that their pupils will flourish. We take up this issue in Chapter 6.

Pupil performance in relation to teacher confidence and other school factors

As noted in Chapter 2, the sample of schools used in the project was the sample selected for participation in the AAP pupil survey in 1993, thus providing the opportunity to investigate any relationship there may be between teachers' confidence and pupils performance. Further, the schools also completed a questionnaire for AAP giving information about their provision for science. The results of the school questionnaire are reported, together with the pupil performances in Stark *et al* (1994) and in SOED (1994c). For the purposes of the Teachers' Understanding Project, the relationships were explored between performance and answers to questions about the time spent on science, the existence of a school policy and the perceived obstacles to teaching science. These concerned science only, of course, and did not include technology. The findings from these two enquiries are reported in this section.

Links between teachers' confidence and pupils' performance

The process of carrying out the investigation of these possible links was, in the event, rather more interesting than the final outcome.

Rather than looking at associations only between overall measures of teachers' confidence and overall AAP science scores, various sub-scores and measures were created so that it was possible to look at relationships which might be masked in overall measures. For instance, would greater confidence in teaching 'living things' be associated with higher pupils performance in items relating to 'living things'? Would confidence in teaching science processes be associated more with performance in processes-based items than in knowledge-based items? Such questions were explored separately for P3/P4 ('lower') and P6/P7 ('higher') teachers. It was also possible to examine relationships between the confidence of lower and upper teachers in the same school as some indication of a school effect.

The initial step was to form justifiable sub-measures on groups of items relating to teachers' confidence. Justification was both statistical and educational. Scores were formed for each item in questions 7, 8, 9, and 10 of the questionnaire (see Appendix 1), by giving each teacher a score of between 1 and 4 according to the alternative chosen. A factor analysis was then carried out to see whether groups of items hung together and, in particular, whether it made sense to form the sub-scales which were based on the Attainment Outcomes, and Strands of the 5–14 Environmental Studies Guidelines. The results were as follows:

Question 7: Teaching across the curriculum

Three groups emerged comprising these subject areas:

7.1 English, mathematics, social subjects
7.2 Science, technology, information technology
7.3 Art, music, physical education, religious education.

The one subject area which did not fit into any sub-group was health education, which interestingly had some affinity with sub-groups 7.1 and 7.3 but not 7.2. The decision was taken to omit health education from the sub-scores based on these groups.

Question 8: Teaching in science and technology

In this question the items had been taken, almost verbatim, from the 5–14 document and thus it might be expected that they would be found to group into the five attainment outcomes (three science and two technology) from which they were taken. There was indeed a clear identity in the case of 'understanding living things and processes of life', which separated cleanly from other items. Among the rest, three factors emerged with some overlap. All the technology items clustered together with no distinction between 'Understanding and using technology in society' and 'Understanding the using the design process'. Thus the four sub-groups which emerged were:

8.1 Understanding Living Things
8.2 Understanding Energy and Forces
8.3 Understanding Earth and Space
8.4 Understanding Technology.

Question 9: Teaching science processes

In this question the items were taken from the stands relating to the science component: planning, collecting evidence, recording and presenting, interpreting and evaluating. The analysis gave just one single factor which could not be sub-divided. Thus for this question we used only the total score for all items.

Question 10: Pedagogic skills

These items were based on the skills required for teaching science and technology 5–14 although not related to specific statements in the guidelines. In the questionnaire they were laid out in three blocks which, although not labelled, were clearly related to planning activities, interaction during teaching and assessing and recording pupils' experience. The analysis showed a clear separation of a group of items relating to 'assessing and recording'. Whilst there was some overlap between the other two identifiable groups, they appeared to be the best sub-grouping. Thus the items in this question were explored in the three sub-groups:

10.1 Planning activities
10.2 Teaching
10.3 Assessing and record-keeping

The scores on these sub-sets of questions and on the questions as a whole were first used to explore in more detail the differences in confidence between teachers of P3 and P4 ('lower') and teachers of P6 and P7 ('upper'). Table 4 11 presents the results of using a paired samples t-test to explore these differences.

Table 4.11: *Difference in confidence perceived by 'lower' and 'upper' primary school teachers*

Scale/sub-scale	Difference between 'lower' and 'upper' school teachers
7 total for 'Teaching across the curriculum'	Not significant
7.1	Not significant
7.2	Not significant
7.3	Lower more confident than upper. Significant at 5% level.
8 total for 'Teaching in science and technology'	Upper more confident than lower. Significant at 5% level.
8.1	Not significant
8.2	Upper more confident than lower. Significant at 5% level.
8.3	Upper more confident than lower. Significant at 5% level.
8.4	Upper more confident than lower. Significant at 5% level.
9 total for 'Teaching science processes'	Upper more confident than lower. Significant at 5% level.
10 total for 'Pedagogic skills'	Not significant
10.1	Lower more confident, but significant only at 10% level.
10.2	Not significant
10.3	Not significant

Table 4.11 shows that only in teaching expressive arts and religious education do 'lower' school teachers express more confidence than 'upper' school teachers. This finds support in the 5–14 primary school evaluation (Malcolm and Harlen, 1994) where teachers express concern about their level of expertise in music, art and religious education, particularly in relation to the requirements at the top of the primary school. In science and technology, however, only in relation to living things is there no difference between 'upper' and 'lower' class teachers. In other aspects, the 'upper' class teachers are more confident than 'lower' class teachers. In interpreting this it must be borne in mind that male teachers express greater confidence in science and technology and that they are more likely to teacher upper primary classes than lower ones (see page 45/46).

The possibility of there being associations between the confidence expressed by upper and lower teachers in the same school was explored for each scale and sub-scale. Only one significant correlation of any meaning was found. This was for sub-scale 10.3: Assessment and recording. A possible interpretation of this result is that in this one area there is a greater school-wide influence than in any of the others explored. Perhaps schools have policies and practices in assessment and recording which give teachers confidence, but do not have such structures to support other aspects of teaching science and technology.

In order to explore possible relationships between teachers' confidence and performance in related aspects of the AAP science tests, sub-scores were formed by categorising the test items as assessing Living Things, Energy and Forces, Earth and Space and Investigation Skills. This allocation was carried out independently by two judges. There was a high level of agreement and differences were readily resolved. Technology was not uniquely addressed by any item but overlapped with several assessing skill or energy and forces. It was not possible

to compute an independent technology performance sub-score. These sub-scores and the total test score on items taken by pupils in the school were then correlated with the teachers' confidence scales and sub-scales, separately for P4 and P7.

The results were less than startling. For P4 there were no correlations of any significance or interest. For P7, although none of the correlations was statistically significant at the 5% level, a few were large enough to be worth noting as having some educational significance. These were:

- scores on items relating to 'energy and forces' were positively correlated with pedagogical skills (Q10 total) and with the sub-scales 10.1 (planning) and 10.2 (teaching)
- overall science scores were positively, but weakly, correlated with Q10 (total pedagogical skills).

Links between performance and certain school factors

The links were explored for P4 and P7 results separately and for a combined science score for each school (the P4 and P7 samples for the AAP science survey were from the same schools). Differences in scores were tested using a two-tail t-test for schools with and without a school science policy, for those spending up to 5% of time on science and those spending more than 5% of time on science, and for those perceiving various obstacles to increasing the time spent on science. The results now follow.

Science policy

62% of schools in the sample had a school policy for science and 38% did not. The difference in P7 science scores for these two groups was significant at the 5% level in favour of those having a school policy. Difference in P4 score were not large enough to be significant, although when P4 and P7 scores were combined the difference remained statistically significant.

Time spent on science

59% of schools spent 5% or less of total class time on science and 41% spent more than 5% for P4 pupils. There was no significant difference in P4 scores between these two groups although those spending more time had slightly higher scores.

51% of schools spent 5% or less of total class time on science and 49% spent more than 5% for P7 pupils. Again there was no significant difference.

Perceived obstacles to spending more time on science

88% of schools perceived the legitimate demands of other areas of the curriculum as an obstacle to spending more time on science, whilst 12 % did not perceive this as a large obstacle. The scores of those schools where this obstacle was perceived were higher than of those where this was not the case and the difference was statistically significant in the case of P7 pupil scores.

22% of schools saw lack of appropriate accommodation as an obstacle to spending more time on science, whilst 78% did not. No statistically significant differences in scores were found.

19% of schools saw lack of resources as an obstacle to spending more time on science, whilst 81% did not. Differences in scores were not significant.

Finally, 69% of schools identified teachers' attitudes, qualifications or confidence as an obstacle to spending more time on science, whilst 31% did not identify this as an obstacle. The latter group had the higher scores but the difference was not statistically significant.

Comment on factors affecting pupil performance

These results can be easily summarised. There were no statistically significant (at the 5% level) associations found in the data between teachers' confidence and pupils' performance on the AAP science tests. The only school-based factors which were significantly related to higher test performance were the existence of a school policy and the perception that the time demands of other subjects were not an obstacle to spending more time on science.

At this point it is perhaps worth making three comments. First, that it is known that pupils' out-of-school experiences have a strong impact on their learning. The fact that the majority of schools spent only 5% of class time or less on science would support the notion that this may have rather less impact on their learning than everyday experience out of school. This may account for so few school variables being associated with differences in scores (a finding wholly consistent with the APU findings for the primary school (Russell, 1988)). At the same time the lack of great variation from one school in matters such as the time spent on science could equally account for the apparent lack of association with performance. A second comment which should be made is that the AAP tests are not able to give a very reliable measure of performance at the school level, since they are designed for monitoring at the national level, not all pupils take all items and only a sample of pupils within each school is tested. We should, therefore, avoid concluding that relationships between performance and confidence, and possibly other school-related factors, do not exist. It was simply not possible to detect them using the data available to us. Third, however, in the light of this, the fact that the existence of a school policy for science was found to be associated with a statistically significant difference in scores is of particular educational significance. It is unlikely that the existence, or not, of a document has in itself any impact, but its existence is indicative of some commitment within the school to teaching science and, plausibly, of discussions of how science should be incorporated in the curriculum and of what might be taught at different stages.

Summary Points about Teacher Confidence

- Primary teachers have much less confidence about teaching science and technology than about almost all other curriculum areas.
- Teachers are reasonably confident that they have the knowledge needed to develop pupil understanding of 'Living Things and the Processes of Life'; but, one-third of teachers say they need significant amounts of advice and help.
- Confidence about having the knowledge to develop pupil understanding of 'Energy and Forces' is lower than for 'Living Things'; more than half want significant amounts of advice and help.
- Confidence about 'Earth and Space' is roughly the same overall as 'Living things ...'; there is a big variation in confidence from one key feature to another.
- Confidence about having the knowledge to develop understanding of technology in pupils is low; it is rather higher on the social aspects of technology than on control and design technology.
- Teachers' confidence about developing science process skills in their pupils is somewhat higher than their confidence overall about developing understanding of science content.
- Although teachers admit to a lack of confidence with aspects of science and technology, they are confident about the deployment of their general teaching skills – even in the areas of science and technology.
- Male teachers are more confident about science and technology than female teachers.
- More recently qualified teachers are more confident about science and technology teaching than are more experienced teachers.
- Teachers with science qualifications in their own educational background are more confident about teaching science and technology than those with little or none.
- Where confidence is low, the level is said to be influenced by these factors:
  - little science/technology at school – or adverse experiences of school science/technology
  - perceived inadequacy of initial training
  - little inservice training, or provision that was not confidence enhancing
  - the ever-widening remit of teachers and innovation overload
  - inadequate resources and support to cope with the practical difficulties of science/technology teaching.
- Many teachers showed a high degree of general professional confidence which allowed them to tackle science and technology teaching with some confidence; however, many of these were unsure that their own understanding would be adequate to facilitate conceptual development in their pupils.
- It was not possible to determine any relationship between pupil performance and teacher confidence.

4.2 ... about teachers' understanding of science

Introduction

As described in Chapter 2, 55 teachers discussed aspects of science with us. There were six science topics or 'events'.

- A1 Arm
- A2 Carbon dioxide
- A3 Mirror
- B1 Water
- B2 Fish
- B3 Circuit

The explanation of each of these was centred on three 'big science ideas' as discussed in pages 21–23. The findings from the collaborative explanation sessions with individual teachers are given in the pages indicated.

- Six topics described in turn p 64
- The misunderstandings revealed by teachers p 87
- The 'understandability' of the eighteen big ideas p 92
- How does the level of understanding vary? p 97
- What can we say about teachers' understanding? p 98

Topic A1 ARM

Teacher confidence on this focus of study was relatively high, with a confidence index of 312 –see page 37.

Relationship to guidelines

Science Attainment Outcome:	Understanding Living Things and the Processes of Life
Strand:	Knowledge and Understanding
Key Feature/Focus of Study:	The structure and functions of the major parts of the body as they relate to the process of movement (muscles, bones and joints)
Stages:	P4 to P6.

The event

The interviewer held his/her right arm parallel to the ground and moved the forearm in towards the body and then back out again. Questions and prompts included the following:

- Describe for me, what is my arm doing?
- How do we explain that our arms can do this?

  Will you start ... or shall I?

Think in terms of bones, a joint and muscles. What do the muscles do?

- This muscle [at the front of the upper arm] is fairly obvious; is this muscle enough to produce the movement?

A crude model (constructed of two bits of wood, a hinge and elastic) was available, to be used in the last stage of the discussion if necessary.

Science Big Ideas

- 1 Bones move at a joint because of muscles.
- 2 Muscles pull; they don't push.
- 3 Muscles need to be in pairs to reverse a movement.

Understanding of the Big Ideas

1 Bones move at a joint because of muscles

Two-thirds of the teachers (18 from 28) quickly showed that they understood that the observed movements of the arm could be explained in general terms by the movement of bones at a joint because of the action of muscles. All of the remainder developed this understanding (or were prompted to recall it from memory) before the end of the discussion. In other words *all* of the teachers either possessed the understanding or could achieve it quickly with little assistance.

The teachers who initially appeared not to have the understanding explained the arm's movement without mentioning the need for muscles. Most frequently they attributed the production of the movement to tendons and/or ligaments.

The tendons are contracting; the tendons do the work.

The tendons and ligaments produce the movement somehow.

It is worth noting that the words tendon and ligament were not introduced by the interviewers, nor do they occur within the Guidelines. Teachers were quite clear that tendons and ligaments were involved in some way or another with skeletal movement, but their functions were something of a mystery.

Less frequently the movement was said to be produced by the brain. It would probably be unfair to call this a misconception. Although teachers seemed to be saying that the brain had a direct effect in causing bones to move, this may have been shorthand for 'the brain sends a message which stimulates a muscle to contract and move the bone'.

The brain sends a message to the bone that it has to move – and so it moves.

2 Muscles pull; they do not push

Less than one-fifth of the teachers (5 from 28) spontaneously showed understanding of the idea that muscles can pull, but not push. Almost all of the others recalled or developed this understanding in the course of the discussion; the single exception provided no evidence of understanding of the idea.

The majority of teachers showed an understanding that muscles contract (or tighten or shorten) and that when they do this they pull on a bone and thus move that bone; they could satisfactorily explain the inwards movement of the forearm

by this action from a muscle (biceps) attached at appropriate places in relation to a joint (the elbow). However, many believed that when a muscle does the opposite of contract, it produced the opposite of a pull (ie it pushes). The composite idea of 'expand and contract' seemed to be familiar to many; some recollected from the early years of their own secondary schooling that gases, liquids and solids all expand and contract – therefore probably muscles should do the same. When gases, liquids and solids expand, they exert forces; it seemed not at all unreasonable that muscles should do the same.

Muscles expand and contract; thus they can pull in and push out.

The same muscle just pushes the arm back out again.

These teachers had thought of the opposite of contract as expand; it was then suggested to them that in the case of muscles the opposite of contract might be relax. The majority immediately accepted this suggestion and then, realising that a relaxing muscle was unlikely to push, quickly abandoned their original conception that muscles can push. The others had no difficulty in retaining the original conception and supported the retention by arguments that seemed to them to have considerable weight and face validity.

The heart muscle pushes blood round the body, so the muscles attached to the arm can push it in and out.

I don't see why a muscle cannot push; you have to push with your arms when you do weight-lifting.

3 *Muscles need to be in pairs to reverse the movement*

One-quarter of teachers showed, without being prompted, that they understood that muscles must be in pairs to reverse a movement. Three-quarters did not, even although they had come to understand that one single muscle could not both pull and push. However, *all* teachers except one developed the understanding during discussion. Understanding was rapidly achieved; in a few cases, the model was said by teachers to be extremely helpful.

Several of our teachers came to a point in the collaborative explanation where they realised a difficulty. They knew that muscles contract and thus pull the forearm in; they knew, or came to realise, that a relaxing muscle would not push the arm back out. Something obviously did this so they posited some kind of device, perhaps like a spring, in the elbow which was able to move the arm when the muscle joined to the forearm was relaxing and not opposing an outward movement.

It bends back because of a wee spring inside your elbow that only works one way.

The forearm gets moved back when the muscle relaxes.

Relaxing is the cause of the movement; the arm springs back when you release the pulling force that moves it in.

A small number of teachers talked of their understanding that there was a muscle in the upper arm that moved the (horizontal) forearm inwards and that there was another muscle (or muscles) in the lower part of the arm which could then move it back outwards.

It's a muscle nearer the wrist that moves the arm back out.

A muscle in the lower arm pulls it back in.

These teachers seemed to have the agonist/antagonist concept, but not to have been told, or thought through for themselves, the location and points of attachment of the outward moving muscle.

The initial demonstration showed the forearm moving in a horizontal plane, ie parallel to the floor; this was quite intentional to make it less likely that gravity would be construed as a contributing force. However, a small number of teachers did suggest that gravity was involved in some way; they offered it as a tentative hypothesis ... 'Perhaps it has something to do with gravity?' Further discussion led to this conception being easily dismissed, but teachers then pointed out that it was one idea worth discussing with pupils – in order to refute it.

Interpolation

It is possible for researchers to become over-serious; in this context a colloquial language usage or a chance, pleasant remark to help the conversation along could be taken as evidence of some significant misconception. Three of our teachers expressed doubts on the ideas developed in the collaborative explanation by asserting that they couldn't be true, because some bodies have no muscles. What did they mean? We leave readers to judge for themselves.

I haven't got any muscles myself.

This was said by an exceptionally slim person and it seemed to be said with serious intent. The statement was offered in justification for not knowing that muscles were essentially involved in skeletal movement.

The pupils may have a muscle at the back of their arms, but I haven't.

The teacher who said this was discussing whether or not the ideas in this topic would be difficult to develop in pupils. It is not possible to determine whether the teacher genuinely believed that a muscle had to be obvious to a viewer for it to exist at all or whether she meant that her pupils would be more easily convinced of the existence and action of muscles from observation of their own bodies.

I have plenty of flesh – but no muscles.

The gentle hilarity caused by this remark distracted the interviewer from asking desirable follow-up questions. (What is flesh? Is meat just muscle?)

Supplementary points

In the consultation exercise on the big ideas (page 19), it was suggested to us that we should look out for three additional things.

1 Is the arm described as a lever operated by forces?

We did not introduce the words 'lever' or 'force'. No teachers used the word 'lever'; two teachers talked about muscles exerting forces – the remainder were happy with 'pull' and 'push'.

2 Do teachers use labels and 'fancy language' unnecessarily?

The answer to (i) above suggests not. However, five teachers did talk unhelpfully about tendons and ligaments. A similar number labelled the biceps muscle

(correctly) and two teachers labelled the triceps muscle (also correctly). We were interested to note that a couple of teachers said they felt they *ought* to know the names of the muscles we were talking about; they would feel happier if they knew the right labels.

3 Did teachers view the arm from a technology perspective?

One of our consultants hoped that teachers would see bones as hollow, tubular structures – light, rigid and strong. No teacher in our sample introduced this idea. One teacher did say that she would approach the topic of movement of the arm from a technology stance; pupils would first build models of the arm with Meccano and rubber bands.

■ Topic A2 CARBON DIOXIDE

Teacher confidence on this focus of study was relatively low, with a confidence index of 245 – see page 39.

Relationship to Guidelines

Science Attainment Outcome:	Understanding Earth and Space
Strand:	Knowledge and Understanding
Key Feature/Focus of Study:	Fossil fuels: occurrence, combustion and effects of emission of 'greenhouse gases'
Stages:	P7 to S2

The event

The interviewer produced a picture, from a children's book, of a coal-fired power station. The text alongside was: 'Burning fossil-fuels like coal, oil and gas releases carbon dioxide into the atmosphere. Carbon dioxide is an important greenhouse gas.' Questions and prompts included the following.

- What source of energy does this power station use?
- Focus on the text beside the picture; how could we explain that burning coal puts carbon dioxide into the atmosphere?

  Will you start ... or shall I?
- All these fossil fuels have got carbon in them. What happens when they burn?
- Carbon dioxide is one of the greenhouse gases. What does this mean?
- Greenhouses get hotter inside than it is outside.

  Can you explain that for me?

Science Big Ideas

- 1 Carbon dioxide is produced when fossil fuels are burned.
- 2 Carbon dioxide in the atmosphere acts like the glass in a greenhouse; the temperature is higher (things get hotter) 'inside'.
- 3 It is easier for light energy from the sun to get in through the carbon dioxide/glass than it is for heat energy to get back out again.

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Understanding of the big ideas

1 Carbon dioxide is produced when fossil fuels are burned.

A small number of teachers (four) immediately showed their understanding of the concept of burning by explaining that the carbon in the coal combined with the oxygen of the air releasing energy and carbon dioxide. By the end of the discussion an additional sixteen had developed, or been prompted to recall, this understanding. Eight teachers displayed no understanding of the idea.

Those who did not initially call on the concept of burning, seemed to possess the alternative conception: carbon dioxide in the coal is released when the coal is heated.

> *The carbon dioxide was inside the fuel and got released when it was* heated.

Many teachers expressed this confidently in these or very similar words. Of these a few, knowing that one burns coal in order to obtain heat, were somewhat troubled by the idea of putting heat *into* the coal. This worry was easily removed by one teacher who argued that things in the coal burned to give us the heat we wanted and some of that heat set free the carbon dioxide. Others equated the heat which is necessary to 'light' a fire with the heat that you need to start releasing carbon dioxide; the carbon dioxide coming out of the coal then gives you the rest of the heat.

Teachers who thought that there was carbon dioxide within the coal waiting to be released, produced justifications of this idea.

> *Plants contain carbon dioxide, therefore fossil fuels release it.*
>
> *Coal is really trees; the carbon dioxide comes out when you burn it.*
>
> *Fossil fuels have carbon dioxide inside them because they were originally plants who took this in from the earth and they are now giving it off again.*

In talking about the release of carbon dioxide from coal, teachers used phrases which may have been triggered by memories of science from the early years of their own secondary education. The two examples which follow hint at distillation, particularly the so-called 'destructive distillation' of coal (ie heating coal in the absence of air).

> *It's a separation process; at a certain temperature, out it comes.*
>
> *Coal is a complex chemical composite of carbon compounds and when you heat it the components are separated and released.*

2 Carbon dioxide in the atmosphere acts like the glass in a greenhouse; the temperature is higher (things get hotter) 'inside'.

A third of our teachers (nine) described without any assistance the greenhouse as a model, or metaphor, for carbon dioxide in the atmosphere. The glass in the greenhouse, and increased carbon dioxide in the atmosphere, both had the same effect: things got hotter 'inside' them than they would otherwise have been. Teachers seemed able to use 'gets hotter' and 'the temperature increases' interchangeably.

A further sixteen teachers developed the understanding, or were prompted to recall it, in the course of the collaborative explanation; the remaining three did not.

There was considerable confusion revealed between the greenhouse effect and depletion of the ozone layer. The single word 'greenhouse' seemed to prompt (for well over a third of our sample) a response involving 'ozone layer'. This kind of confusion is well-documented. See, for example, Johnstone (1993) and Boyes and Stanisstreet (1993).

> *The greenhouse effect is all to do with destruction of the ozone layer.*
>
> *Greenhouse gases link in with ozone layers.*
>
> *Atmospheric pollution is all the same sort of thing really; the earth is warming up because of the ozone layer.*

Not all our interviewees just stated there was some connection; several attempted to define the relationship or to question any too easy assumption of a connection.

> *Carbon dioxide is a cfc. Oh no, it isn't. And the ozone layer is breaking down. I'm not sure if that has anything to do with carbon dioxide or not ...*
>
> *I confuse the greenhouse effect with holes in the ozone layer; however, I do know the greenhouse effect isn't really the holes – rather the opposite.*
>
> *The greenhouse effect is related to the ozone layer. The carbon dioxide forms a layer in the atmosphere. I think that it ought to escape through the holes in the layer; if the two help to cancel each other out, that can't be a bad thing.*

About a quarter of the teachers offered a quite different reason for carbon dioxide being called a greenhouse gas. It is so-called because a greenhouse traps carbon dioxide inside it; the atmosphere is like a greenhouse, because it also traps carbon dioxide.

> *Carbon dioxide is a greenhouse gas, because plants give off CO_2.*
> *The greenhouse and the atmosphere are both like a prison for carbon dioxide.*

It is worth noting that the teachers producing this conception all used the idea that the plants in the greenhouse produced carbon dioxide. However, they seemed to reach that idea by two different routes. Some remembered that plants had 'something to do with carbon dioxide' and then moved to the decision that they must *produce* it, because that was the conclusion they needed. An equal number recalled that plants *take in* carbon dioxide (photosynthesis) and also breathed it out (respiration): they then concluded that respiration must produce more carbon dioxide than photosynthesis uses up.

3 ***It is easier for light energy from the sunlight to get in through carbon dioxide than it is for heat energy to get back out again.***

In looking for an explanation as to why it got hotter inside a greenhouse, we wanted to find out if teachers would show understanding of the idea that it must be easier for energy to get in than to get back out again. We did not look for an explanation in terms of frequency and wavelength, but rather for some grasp of

the notion that light energy from the sun finds it easier to go one way than heat energy does to go the other.

One teacher gave us this kind of explanation without any prompting; a further eight developed this understanding in the course of discussion. Two-thirds of teachers gave us no evidence of understanding the idea at any time. A very large number of teachers said this was one of those things they just took for granted: no-one had ever asked them *why* before – they hadn't seen this as something that needed any explanation.

A few teachers argued that the glass of the greenhouse attracts the sun and then heats up the inside of the greenhouse. These teachers suggested a two-step mechanism which did not take into account that energy from the sun could travel through the glass.

The greenhouse attracts the sun's rays and then the inside gets hotter.

Energy is trapped by the glass, which then heats the air inside.

A similarly small number of teachers explained the greenhouse effect – for the greenhouse itself and in the atmosphere – in terms of the prevention of cold travelling. These teachers knew there was a beneficial aspect of there being carbon dioxide in the atmosphere: 'our planet would be too cold without it'. They then saw a greenhouse as another helpful device to protect living things from the cold. 'Cold' was reified by these teachers into a thing with damaging effects.

A greenhouse helps plants to grow by protecting them from the cold.

The greenhouse doesn't cool down until you open the door and let the cold in from outside.

Interpolation

There are two aspects of teachers' thinking not directly related to the three 'big ideas' that deserve a little note.

1 A few teachers showed incidentally that they held a 'misconception' about which biology teachers have strong views: we breathe in oxygen and breathe out carbon dioxide.

Plants are like us; when we breathe air in it's oxygen and then you breathe out carbon dioxide.

This raises an interesting pedagogical problem. Is this a simplification which can justifiably be taught to primary school pupils on the grounds of its 'graspability'? Or is it an error which inhibits the later development of pupils' understanding?

2 Two of our teachers clearly possessed a conception of the earth as a whole being a living organism, ie an animist, Gaia conception of the nature of our planet. We, as human beings, breathe out air with more carbon dioxide in it; plants produce carbon dioxide; fossil fuels derived from plants release carbon dioxide into the air when they burn. But more than this behaviour of the inhabitants and constituents of the earth, the earth **itself** can be construed as behaving like a living thing.

I think more in terms of the earth as a whole breathing; fossil fuels give off carbon dioxide, just like plants and ourselves …

Carbon dioxide comes from the fossilising and breathing processes of the earth …

Supplementary points

It was suggested to us that we look out for four additional things. It is important to remember that we did not *seek* data on these issues.

1 Do teachers recognise that some 'greenhouse effect' is essential for life on earth? Four of our teachers provided evidence of knowing and understanding this.

2 Do teachers realise that there is a small amount of carbon dioxide in the air and that therefore a small addition may have a large effect? None of our teachers revealed this understanding.

3 Is it realised that carbon dioxide is not the only greenhouse gas and that there is debate as to whether it is the most important one? Two teachers showed their understanding of this.

4 Is there confusion between the greenhouse effect and ozone layer depletion? Undoubtedly there is; it was spontaneously revealed by well over a third of the sample.

■ Topic A3 MIRROR

Teacher confidence with respect to this focus of study was about average, with a confidence index of 252 – see page 38.

Relationship to Guidelines

Science Attainment Outcome:	Understanding Energy and Forces
Strand:	Knowledge and Understanding
Key Feature/Focus of Study:	Mirrors and reflections, including curved mirrors
Stages:	P4 to P6.

The event

The interviewer produced a rectangular plane mirror (about 10" x 7", made of flexible material with mirrored surfaces) and a plastic model of a dinosaur. The model was placed in front of the mirror in such a way that the teacher could clearly see both the model and its reflected image in the mirror.

The interviewer also had two small glass mirrors. The original plan was that discussion would be extended to cover an explanation of how a periscope worked and the type of image to be seen in a curved mirror. In only a very few cases did time allow for these extensions to the discussion; their number does not allow reporting with any confidence so, reluctantly, these aspects are omitted.

Questions and prompts included the following.

- What did you see?
- How could we explain how we see the model … and how we see the reflection?

Will you start … or shall I?

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- How does light get from the dinosaur to your eyes?
- Where is the reflection?
- Why does it appear to be there?

Science Big Ideas

- 1 To see an object, light from it has to enter the eye.
- 2 To see a reflection, light from the object bounces off the surface of the mirror before getting to the eye.
- 3 The brain 'assumes' that light has followed a single straight line (from behind the mirror), even if it has been reflected on the way.

Understanding of the Big Ideas

1 To see an object, light from it has to enter the eye.

A third of teachers demonstrated their understanding, without any prompt, of vision depending on the travel of light from an object to the eye. All of the rest of the teachers developed or revealed this understanding during the discussion.

About a third of teachers said things which led us to think that they conceived of seeing things as sending something out of their eyes.

> *The light from your eyes focuses on what you are looking at.*
>
> *I'm throwing the light from my eye onto the [model] dinosaur.*
>
> *I make my eyes look at it; I focus my eyes on it and then I can see it.*
>
> *My sight is travelling between me and the dinosaur.*

This alternative conception exists in the minds of many children and is perhaps reinforced by pictures showing rays shooting out of people's eyes and detecting distant objects by a kind of radar. It was fascinating for us to discover how frequently the conception was held in our sample of teachers and how surprised people looked when the conception was questioned. It seemed as if these teachers felt there was nothing here that *needed* to be explained: 'We see things – obviously – because we look at them'. In the collaborative search for explanation, several teachers talked of realising for the first time that there was something amazing or wonderful in being able to apprehend the existence of things at a distance from them.

One teacher gave a detailed and accurate account of the role of light in seeing and then added:

> *I do remember thinking that 'looking' was to do with things coming out of my eyes ... probably until quite recently ...*

2 To see a reflection, light from the object bounces off the surface of the mirror before getting to the eye.

Over half of the teachers were able to explain that seeing a reflected image meant that light from the object had 'bounced-off' the surface of the mirror before it reached the eyes. A third developed this understanding during the collaborative

pursuit of an explanation; few of the teachers produced no evidence of their understanding of this idea. It is worth noting that several teachers who had not *initially* understood the first idea quickly showed their understanding of this second idea; in other words having acquired a prerequisite understanding, the acquisition of the additional understanding was straightforward and rapid.

Those teachers who did not produce the orthodox explanation tended not to have an alternative; they said they just didn't know and asked for assistance. However, two people started from their observation that the reflection showed them the *back* of the object, which they could not see directly; this led into their conceiving the idea that the mirror provided illumination for the reverse side of the model dinosaur. This conception resisted modification when these teachers were asked to trace the probable path of the light with a finger.

> *I can see the back of the dinosaur; that's because it is illuminated by light bouncing off the mirror.*

Another two teachers explained reflection by the bending of the light somewhere, ie there was some confusion in their minds between reflection and refraction.

> *It's all to do with the bending of the light ...*
>
> *This is because of refraction; it's like the fish in the water which seems to be where it isn't; the dinosaur isn't really behind the mirror – but it seems to be.*

3 ***The brain 'assumes' that light has followed a single straight line (from behind the mirror), even if it has been reflected on the way.***

None of our teachers gave an explanation, unprompted, of why the reflected image appeared to be the same distance behind the mirror as the object was in front; about a quarter developed clear understanding of this as the discussion proceeded. The remaining three-quarters shared no development of understanding or gave up on the search – often expressing the view that they understood it really, but it was just too difficult to find satisfying words to express their understanding.

A number of teachers (five) were quite clear in their own minds that the reflection (of the model dinosaur) was a 'thing' that could be located in a definite place. To some extent, the words of the interviewers prompted an initial response in these terms: the natural response to 'Where is the reflection?' is to attempt to locate it somewhere. The majority of teachers moved, without interviewer intervention, to talking about where the reflection *appeared* or *seemed* to be; we have not included these teachers amongst those holding this conception. A few teachers persisted with the conception that the reflection must actually *be* somewhere.

> *The reflection is* ***there*** *– on the surface of the mirror.*
>
> *The reflection is* ***on*** *the mirror; no – it's* ***in*** *the mirror; no, it's not – it's* ***behind*** *the mirror.*

The conception that the reflection was located on the surface of the mirror seemed quite resistant to change, two teachers were sure that they could point to the place on the surface where it was located. Teachers who said the reflection was *behind*

the mirror and were then asked to point to where it actually was, first moved their hand to point to a location behind the mirror, then quickly said 'Of course, it isn't *really* there – but that's where it looks as if it is ...'.

The difficulty in finding the 'right' words to talk about this idea was very real; in many interviews there was tremendous concentration by both teacher and interviewer on the search for effective communication. For example, one teacher was very concerned about the difficulties of developing the idea of reflection in pupils. She then hit on trying to explain to pupils what they see in mirrors, by asking them to visualise other real objects being at the same distance behind the mirror as they were in front and, in addition, the mirror being transparent.

Seeing a reflection is as if we were looking through glass ...

This led to an intense discussion of whether one's image in a mirror looks the same as 'seeing oneself' through a pane of glass; would, for example, one's left hand appear to be on the left in both situations? The teacher closed this with a rapid decision that the topic was even more difficult than she thought, so she would try to avoid teaching it; she clearly felt some discomfort at having conceptions challenged.

Interpolation

What did one teacher mean when she said 'it's very much easier to see sound than it is to see light'?

Supplementary Points

We looked out for three additional things.

1 Did teachers refer to light as an energy form? No teacher mentioned this; the topic did not make it necessary.

2 Did teachers distinguish between the eye as a receiver and the brain as the interpreter? By the time the role of light in seeing had become clear (as it did in 24 cases from 28), most teachers had made it clear that both eye and brain were necessary to 'see' something, but the role of each was not defined; we did not push for any definition.

3 Did teachers talk about the differences between object and reflected image in terms of, for example, left and right or correct/wrong way up?

On the whole they did not, although we have described above one interesting case where a teacher did. However, several teachers mentioned the richness of this topic for *description* by pupils of exactly what they observed using a wide variety of objects (including words written on cards) and a range of different mirrors. We were left with a distinct impression that teachers would enjoy teaching this topic, just as long as pupils did not ask 'why?' questions.

■ Topic B1 WATER

Teacher confidence with respect to this focus of study was high, with a confidence index of 329 –see page 39.

Relationship to guidelines

Science Attainment Outcome:	Understanding Earth and Space
Strand:	Knowledge and Understanding
Key Feature/Focus of Study:	The water cycle (in simple outline) introducing water as a gas, melting, freezing, evaporation, condensation
Stages:	P4 to P6.

The event

The interviewer poured water and ice-cubes from a thermos flask into a small, shiny-sided tin. Questions and prompts included the following.

- What do you see on the side of the tin?
- How could we explain this?

  Will you start ... or shall I?
- What is happening to the ice?
- How could we explain this?
- What *is* condensation?
- Where did it come from?
- Water exists in three states; what are they?
- Could we explain these changes in terms of energy?

Again the discussion had observation and explanation phases. We were not concerned to get all the observations first before moving on to explanation; we expected the two to weave in and out – and they did.

Science Big Ideas

- 1 Water (as a gas) from the air changes to a liquid when it meets a cold surface.
- 2 Water can exist as solid, liquid or gas.
- 3 Gas changes to liquid when heat/energy is taken out; solid changes to liquid when heat/energy is put in.

Note: We have given the big ideas in this sequence because we expected idea 1 to be dealt with first (it applies to the first observation made) and idea 3 to be dealt with last (it covers both condensation and melting). However, some understanding of idea 2 is needed to understand 1; or conversely, once you have developed understanding of idea 1 you have necessarily acquired some understanding of idea 2. This has given some difficulties in analysis and reporting which we would have avoided by focusing on, say, condensation alone; however, the topic would then have been less productive to discuss.

Understanding of the Big Ideas

1 Water (as a gas) from the air changes to a liquid when it meets a cold surface.

Ten of the twenty-seven teachers showed, without prompting, that they understood the concept of condensation, ie the cloudiness on the cold surface was

water (as a liquid) that had come from water (as a gas) in the air. All of the rest of the teachers showed this understanding in use during the discussion.

The most frequent answer to the question, 'What's on the outside of the tin?' was 'condensation'. It is such a common language usage to describe the *substance* as condensation, that we did not consider this as a misunderstanding; it seems pedantic to insist on all occasions that condensation is the process and not the product. Fourteen of our teachers when asked 'But what *is* condensation?' were quite clear that it was water – just ordinary water in its normal liquid state. However, almost half of the teachers indicated that the stuff, condensation, was something other than ordinary liquid water.

The steam effect on the tin is water vapour.

It's wet stuff, that isn't actually running water yet.

It looks like steam; it's a vapour – it's a mist or moisture; it's water not quite as a liquid.

A small number of teachers explained the occurrence of the 'mistiness' without any reference to the existence of a substance; the mist/cloud/condensation was an effect which could be explained in terms of temperature differences alone.

It's when you have two different temperatures and you get a reaction between the two.

One is colder than the other ... and that's what happens when the two meet ...

That effect comes from the reaction of hot and cold.

Perhaps there is something here that deserves more thorough exploration. It may be that a few teachers conceive of hotness and coldness as things which can meet, react and form some other thing.

There were also a few teachers in our sample who suggested that the water on the outside of the tin had come directly from the inside.

The water from the surface inside the can is evaporating and then condensing when it meets the colder surface outside.

Of course it is likely that *some* of the water that condenses on the outer surface was previously inside the tin and first evaporated, then mixed with water already in the air and some of that then condensed. However, these few teachers seemed to be suggesting a much more direct route which did not mention that there was any involvement of the water in the air.

One teacher initially conceived of the most direct route.

The water is coming through the sides of the tin?

When asked if this was the most likely explanation, she replaced this conception with another.

Well, the water on the outside comes from the ice-cubes melting.

2 ***Water can exist as solid, liquid or gas.***

Did our teachers understand that water could exist as solid, liquid or gas? The simple answer to this is 'yes'. Over 80% either showed this understanding directly, or had developed the idea, or were helped to recall it, by the end of our talk.

This answer is too simple. Most teachers 'knew' that there are three states of matter: solid, liquid and gas. They could apply this to water: water can exist as a solid (ice), as a liquid ('ordinary' water) and as a gas (water vapour). However, they could possess this conception and at the same time hold the idea that there was another state – somewhere between liquid and gas. Two examples of this have already been given; there were others.

> *It's water vapour that's in the air … mid-way between gas and liquid; it's actually very small drops of water that you can't see as drops.*

The word 'vapour' was therefore not always seen as a synonym for water-as-gas. It was used to label that in-between state for water. Things could get really confusing when the word 'steam' was also introduced.

> *Condensation is water-vapour; evaporation is the opposite, when you see the steam coming off the streets.*

We are driven back to asking what it means to understand an idea like this. Can we say a person 'really' understands if that understanding cannot be used to identify and remedy related misunderstandings held at the same time?

It is not easy to distinguish alternative conceptions in this area from the use of a variety of alternative words, sometimes interchangeable and sometimes not. The very richness of the vocabulary to discuss 'water' was very obvious in what our teachers had to say. The words included, amongst others, wetness, dampness, moisture, mist, cloudiness, vapour and humidity. The familiarity of many of these words to pupils poses interesting problems, and opportunities, when teaching to develop the scientific concept of 'states of matter'. Teaching for concept development cannot be divorced from the teaching of language.

It should be pointed out that teachers had no difficulty whatsoever with 'solid': ice is a solid; the stuff in which it floats is a liquid. This suggests it might be wise to approach the water cycle from melting and not condensation.

3 ***Gas changes to liquid when heat/energy is taken out; solid changes to liquid when heat/energy is put in.***

Teachers were asked to explain condensation and melting in terms of energy; we wanted to gauge their understanding of the idea that you need to take energy out of a gas to change it into a liquid and that you need to put energy into a solid to change it to a liquid.

Teachers experienced a lot of difficulty with this initially. Only two of the sample displayed and used their understanding without any assistance. However, by the end of the discussion two-thirds had developed or revealed understanding. The rest did not achieve understanding of the idea.

Teachers had no problems with 'hotter' and 'colder' and very little with 'higher temperature' and 'lower temperature'. The iced water was colder than the air; the air was at a higher temperature than the surface of the tin. The difficulty in developing understanding lay in moving from this to the idea of energy moving from one region to another. It seemed as if the gains in understanding were made easier by thinking firsts of heat moving into solid things. Teachers said it was much easier for them to conceive of putting heat into a solid, than taking it out of a gas. (Several teachers confessed to us, quite spontaneously, that although it was obvious how a cooker worked they had never understood how a refrigerator could work. How you could have a refrigerator which ran on gas was wholly baffling.) The transition from understanding the movement of heat to giving explanations in terms of energy was relatively easily accomplished by some – but by no means all.

Some of our teachers possessed the conception that for things to change from one state to another, the temperature must go up or down. It is perhaps easiest to think of this as what teachers believe when they do *not* have the concept of latent heat. (This is the energy involved in changing the state of something, when there is no change in temperature.) Thus, to melt ice you raise its temperature; to get water vapour to condense you just lower its temperature. Another feature of this conception is that if you hold it you cannot explain how two states of matter can co-exist at the same temperature.

> *Things change their state when the temperature goes up and down.*
>
> *Heating something always means increasing its temperature.*
>
> *Ice changes to water; that just happens ... you don't have to put heat into it unless you are in a hurry.*
>
> *The ice must be colder than the water ....*

A few of our teachers, when it was put to them that water as a gas gives out energy when it changes to water as a liquid, related this to their conception of gas as a fuel which releases energy when it burns.

> *The energy that a gas has shows in the explosion when it burns.*

Holding this conception means that no distinction can be made between the kinetic energy of the particles in a gas and the energy of the gas released in the exothermic chemical reaction when new substances are formed. It was possible for these teachers to hold on to their conception even when they were clearly aware that water does not normally burn or explode; a property of one gas, say coal gas, was assumed to be true of gases in general.

> *Gas gives you heat, therefore it has more energy. I have noticed from my gas bill that it's really the energy that you have to pay for.*

The ability to provide an illustration of 'energy-in-gas' extended to providing an illustration of 'energy-in-liquid'.

> *The energy in a liquid can be seen in what it does when it freezes and is strong enough to produce burst pipes.*

Is this a misconception? We are not sure ...

Interpolation
We say at various places in this chapter that things seem to get difficult whenever the concept of energy has to be used.

One of our teachers was convinced that the idea of energy being involved in changes of state was far too difficult for primary pupils ever to understand. However, the concept of heat was seen to be much simpler than that of energy. This was thought by the teacher to be due to the 'fact' that pupils can *see* heat, but they cannot see energy. Energy is something that people feel they have (or not) and can never see; heat, argued the teacher, can be seen in such things as gas flames and the red-hot bits of radiant heaters and toasters.

If one is going to develop the concept of energy in primary pupils, clearly it needs careful thought. We have already encountered one challenge: is it easier to see sound, than to see light? Is it easy for pupils to see heat, but not energy?

Supplementary points
We were asked to look out for two things.

1 Are teachers confused about vapour, clouds and steam?

Yes – see (2) above.

2 Is condensation usually seen as a product, not a process?

Yes – see (1) above.

■ Topic B2 FISH

Teacher confidence on this statement was around average, with a confidence index of 260–see page 37.

Relationship to guidelines

Science Attainment Outcome:	Understanding Living Things and the Processes of Life
Strand:	Knowledge and Understanding
Key Feature/Focus of Study:	Adaptation to the environment over a period of time, leading to an understanding of the process of evolution and the survival or extinction of species.
Stages:	P7 to S2.

The event
The interviewer showed two large colour photographs of very different fish in clearly different environments; one featured a flat fish, well-camouflaged and near the sea-bed, the other a symmetrical free-swimming fish. Questions and prompts included the following.

- Describe for me the differences you see between these two.
- Can we together explain how these fish have come to be so different?

  Will you start ... or shall I?
- Are the differences related to where they live?
- Were fish *always* this different? How did it all start?

- What differences were likely to continue over generations?
- This evolution is a slow process; what would happen if the environment changed quickly at some stage?

Science Big Ideas

- 1 The differences are helpful in the different environments in which the fish live.
- 2 There are chance differences within a generation that can be transmitted to the next generation.
- 3 Evolution occurs over time, because of the selection of those inherited differences which are helpful for survival.

Understanding of the Big Ideas

1 The differences are helpful in the different environments in which the fish live.

All the teachers (27) linked the differences they observed to the animals' environment and recognised that they were helpful in enabling the fish to survive.

We could not help noticing that teachers showed very different behaviours in the observation phase. Some very quickly spotted one or two important differences and immediately moved on to how they would relate them to ideas such as escape and camouflage, 'making things difficult for predators'. Others spent much longer on very careful observation, listing six or seven features and commenting helpfully on whether certain inferences from the observations would be defensible; for example, they were tempted to say something about the relative size of the fish and then decided against this, as these were photographs. These latter teachers appeared to see observation as something to be considered in itself, not just as a quick necessary precursor of other activity.

2 There are chance differences within a generation that can be transmitted to the next generation.

When the discussion moved on towards explanation of the differences, three teachers quickly showed that they already held the scientific view of the role of chance, genetic changes. A further fifteen appeared to develop this understanding by the end of the conversation; initially, however, this vital element was omitted.

Teachers' views could be grouped in three types.

- 'It's all part of nature.'
- The environment has caused adaptation.
- The need to eat to survive has caused changes.

It's all part of nature

> *The fish would be just as different millions of years ago.*
>
> *They have probably always been that different; there has always been a wide variety of living things. That is just the way things are ... that's how life goes. It's nature's way of taking care of itself.*
>
> *They were designed that way by the Creator.*

The core idea in these 'explanations' is perhaps an assertion that there is really nothing there that deserves any kind of scientific explanation at all. 'Observe, marvel and accept' is a wise thing to do on occasion, but one should recognise that the sequence has to be justified on other than scientific grounds.

The environment has caused adaptation

This view was expressed in the early phases of the discussions by over half of all teachers, by more than that if one sees the next group as also belonging here.

> *It's just the environment that makes them different.*
>
> *Animals have evolved because of the demands where they live. If the environment changes, animals adapt to it.*
>
> *Because the fish lives there, it has to have these features; the fish has adapted to what suited it.*
>
> *They develop differently in different places ... they live in different conditions; this makes them different, they need to change.*

The essential idea here is that the environment puts some kind of pressure on the organism and that the organism responds by changing in an appropriate way. This conception was so common that we are obliged to look at it very carefully and question whether it really involves an alternative conception at all. Taken over a long enough time-scale, perhaps evolution is not unreasonably summarised as adaptation to the environment; pressure of the environment does not, however, seem an adequate explanation of how variations are produced within a generation.

The need to eat to survive has caused changes

This category is related to the previous one: what there is available to eat is a feature of the environment. However, in the examples under this heading, teachers were quite explicit that changes in the fish were brought about by the need to eat, the better to survive. Perhaps this is a teleological justification for changing, rather than the description of a mechanism by which change is brought about?

> *The fish have adapted so they can feed better.*
>
> *Survival of the fittest – it's all to do with food chains.*

3 ***Evolution occurs over time, because of the selection of those inherited differences which are helpful for survival.***

Four teachers showed their understanding, without any kind of prompting, that there is a selection of those inherited differences which are helpful for survival and that over an extended period of time this natural selection leads to what is called evolution. A further six developed or revealed this understanding as the discussion continued. Seventeen teachers were either unable to offer any explanation at all, or did not see there was anything to explain, or retained various alternative ideas.

There was some confusion between evolution and other concepts.

> *The tadpole evolves into a frog.*

The fish have sought out environments which suit their differences.

When an animal goes into a different environment it adapts to suit; plaice go black and white on a chess board and the chameleon has a nervous breakdown on tartan.

Natural selection is like selective breeding to produce the characteristics to help them to survive.

Others concentrated on the passing on of successful adaptations implying a time scale very much shorter than an evolutionary one; this seemed to be related to seeing evolution as a thing which applied to an individual – rather than to a population.

The ones who survive have adapted; because they have survived, the adaptation becomes a feature.

The fish adapts to the environment and then the adaptations are inherited.

We found it interesting to note that in this topic there was a high frequency of offering a label as an explanation; this applied in both the second and third of the big ideas. Labels included adaptation, survival of the fittest, natural selection, selective breeding, evolution. The labels were often used appropriately, but the teachers using them found it difficult to elaborate on what they meant.

Supplementary points

We were asked to bear three questions in mind.

1 Are teachers able to translate 'survival of the fittest' into terms of Darwinian theory?

'Survival of the fittest' is one of those phrases that are used as a label, rather than an explanation. The use of the phrase is expected to close the search for explanation; teachers found it difficult to elaborate on the idea.

2 Do teachers understand the decline and extinction of species?

There was not time to explore this with all teachers. When we did discuss this, teachers had no difficulty with the concept. If there is a rapid environmental change, they said, evolution is so slow that the species will decline – and may become extinct.

3 Do teachers distinguish between a living thing changing as it moves from one environment to another and a slow process of adaptation?

We have dealt with this above. Teachers do not find this distinction an easy one.

■ Topic B3 CIRCUIT

Teacher confidence with respect to this focus of study was relatively low, with a confidence index of 238 – see page 38.

Relationship to guidelines

Science Attainment Outcome:	Understanding Energy and Forces
Strand:	Knowledge and Understanding
Key Feature/Focus of Study:	Construction of battery operated circuits to operate eg lamps
Stages:	P4 to P6.

The event

The interviewer laid out a battery, bulb, connecting wires and a switch. S/he demonstrated an assembly in which the bulb did not light (because there was no circuit), another in which the bulb did light and a third in which the bulb did not light, but would if the switch was closed. These situations were discussed with the teacher. Questions and prompts included the following.

- The bulb is not lit; how could we explain that?

  Will you start ... or shall I?
- The bulb is lit; how could we explain that?
- Why is the bulb not lit now? What does a switch do?
- Can we explain what's happening in this circuit in terms of energy?

Science Big Ideas

- 1 For an electric current to flow, there has to be a circuit of materials, each of which allows electricity to flow quite easily.
- 2 Switches make (complete) and break the circuit.
- 3 The battery supplies electrical energy which the bulb changes to light/heat energy.

Understanding of the Big Ideas

1 For an electric current to flow, there has to be a circuit of materials, each of which allows electricity to flow quite easily.

Twenty (out of twenty-seven) teachers demonstrated their understanding of the principle of an electric circuit without any assistance from the interviewer; all but one of the remainder developed or revealed this understanding as the discussion continued.

Some teachers believed that not only has a circuit to be complete, its components have to be assembled in one particular order or the current does not flow.

> *Things have to be wired up in the right order; you start at the positive terminal and work round from there ...*
>
> *If you reverse where you start, then the current wouldn't flow.*

What these teachers may have been taught as a useful procedural convention for setting up a circuit seems to be remembered as a necessary feature for any circuit

to operate; this suggests that the concept of circuit is not well-developed. (Many of our teachers were clear that sign conventions, positive and negative, were important within electricity, but were not clear why and when they were important.)

Two teachers found it difficult to decide whether a circuit existed because they had the conception that some metals conduct electricity and they couldn't remember which did and which did not.

> *I don't know which metals conduct, off the top of my head. I'd look it up and see which did and didn't before I taught this.*

This is an interesting example of a teaching situation where not possessing the orthodox science conception ('All metals conduct.') makes the teacher's task of preparation to teach more demanding than it would otherwise be.

2 ***Switches make (complete) and break the circuit.***

Two-thirds of the teachers showed clearly that they understood what a switch did within the circuit: when open, it introduced an air gap across which current did not flow; when closed, the circuit was complete. The remainder, with one exception, developed this understanding with very little assistance (or revealed it with a small amount of prompting). The single exception (who was the exception also in idea 1) was a teacher who seemed to have a deep block against thinking about any aspect of electricity; she claimed she did not understand anything about it and was certain that thinking about it would never provide her with any understanding.

At least initially, several teachers had the conception that electricity could flow easily through air.

> *It is easy for electricity to flow in air – it just jumps across any gaps.*

Teachers supported their conception by quoting the action of lightning and recent publicity given to the dangers of young children playing near high-tension electric cables.

Two of the teachers had no difficulty in reconciling their conception with the action of the switch in the simple circuits we used.

> *There is nothing in the gap in the switch.*

Thus electricity could not flow; if there had been air in the gap, the electricity would just have jumped the gap – 'it is easy for electricity to flow in air'.

The conception that electricity flows easily through air led in one teacher to a typically Thurber-esque confession.

> *Why the electricity doesn't just jump out of the plug-holes has always been a mystery to me.*

3 The battery supplies electrical energy which the bulb changes to light/heat energy.

Only a small number of teachers were able without prompting to show that they understood that the battery supplied electrical energy which the bulb then changed to heat/light energy. However, by the end of our short discussions two-thirds had developed this understanding – or perhaps came to realise that the understanding the interviewer expected of them they did in fact possess all along. The *level* of understanding required may have to be made explicit. Six teachers did not seem to possess or acquire any understanding of this idea and in three cases we were unable to make a judgement about understanding.

Teachers appeared to be happy and relaxed abut this topic until the area of this third idea was approached. There was then a general realisation that we were getting into deep waters. Teachers were well aware that there are questions about the nature of electricity to which they had no answers that satisfied themselves; they thought it unlikely that anyone else had the answers either.

If you understand the nature of electricity, that makes two of you: you and God.

The interviewer introduced the word energy into the discussion. This prompted many teachers to remember or detect a difficulty: is the electrical current that runs round the circuit the same as the electrical energy that the battery supplies?

Two teachers were quite sure it was.

The battery supplies the energy; the battery supplies the current ... well, the current is the electrical energy.

... so the electrical energy is flowing round the circuit ...

Another could show that she understood the distinction, but was sure that it would not be profitable to attempt to disentangle the two ideas for the primary school stage.

Some of our teachers pictured a battery as containing electricity which is given out until the battery is empty.

The battery just empties out its electricity until there is none left.

This conception seems easy to square with familiar practical experience.

Batteries run down; you can either fill them up again or throw them out.

Teachers holding this conception did not see electricity as flowing *through* the battery, even although they recognised the battery as a necessary part of the circuit. The current comes out of one side of the battery and is either used up as it goes round the circuit – 'it just drains away as it's used up' – or it collects at the other side of the battery where it can't be used again.

Some teachers, it must be clear, were well able to describe an electric current in terms of the movement of electrons and they understood the place of electrons within the structure of the atom. However, even the teacher with the most impressive grasp of all these matters ran into difficulties when trying to make her understanding wholly explicit. She had described the battery as the energy-provider (which shoves the electrons round the circuit) and the current as a flow

of negatively-charged electrons. She then wanted to say what the direction of flow was and recalled that opposite charges attract.

> *... electricity is negative therefore it moves towards the positive terminal; oh, wait a minute – is it positive because the electricity has already left it?*

Readers will be asking by now if we really expected primary teachers to navigate these dangerous conceptual waters successfully. No, we did not; they jumped – we did not push. We wondered if teachers would understand that a battery supplied energy which the bulb changed into light. Teachers had a keen awareness that electricity is one of those topics which lends itself to awkward questions and seemed to want to show their awareness of the potential difficulties; they recognised the difficulties – and they recognised the limits of their understanding.

Interpolation

When asked what the battery was doing, one teacher said it was a source of potential energy. She knew that batteries had something to do with potential difference; batteries have chemical energy which is 'stored' ready to be used in future; therefore batteries give/have potential energy.

If she had checked in common text-books some would have confirmed she was right: chemical energy is seen as a form of potential energy. Others would have said she was wrong: potential energy only applies to things which might fall off (energy due to position) or which, like a spring, have had energy put in to change their configuration.

Is this teacher the possessor of a misconception? Or does she hold a scientific conception held by some science authorities and not by others?

Supplementary points

We were asked to look out for two additional things.

1 Do teachers understand the significance of positive and negative signs?

Teachers knew that the signs were significant, but infrequently remembered what the appropriate conventions were. A few teachers were unsure of the force of the conventions. Were they *mere* conventions, which you could ignore if you understood what you were doing?

2 Did teachers use the terms conductor and insulator?

About a third of our teachers introduced these terms in considering the first of three big ideas. Those who chose to use the words, used them correctly except in one case: one teacher used the word resistor for insulator.

■ The types of misunderstanding revealed by teachers

In the topic-by-topic descriptions, we referred to the misunderstanding and revealed by teachers. We should perhaps first ask if 'misunderstandings' is the best word to use; if different people all make sense of the world in different ways that have equal validity then there are no misunderstandings – only alternative conceptions. However, the teachers' ideas that we describe are not *merely* different, they are different from those ideas that 'expert' opinion currently accepts as the best for a particular purpose and in a given context. The ideas are

not just different from conventional ones; there is a sense in which they are 'wrong' because they do not fit the available evidence. We thus decided we could not shrink from using the term 'misunderstandings'.

The teachers we talked with produced a large number of misunderstandings. We have classified them for this section into seven types:

- use of a label, thinking it an explanation
- giving an inappropriate analogy
- attributing properties that do not correspond with reality
- proposing a mechanism for which there is no evidence
- equating everyday language with scientific language
- believing that 'some' means 'all'
- thinking that scientific explanation is not necessary.

It may be thought that the production of this categorisation is an interesting enough exercise, but one of little practical value. However, as suggested later, an appreciation of the nature of teachers' misunderstandings can illuminate consideration of the kinds of professional development activity for teachers that are most likely to be productive.

Use of a label, thinking it explanation

This was common in our discussions and occurred in all six topics. In response to the question 'Why might that be...?' teachers said 'It's ....' followed by one or two words. They seemed to think that a quick brief answer would be sufficient and they expected it to close the interaction. Calling this one type is misleading; at least two different things are covered by 'labelling'.

1 *I Why has the surface gone cloudy?*
T It's condensation.

Here the teacher rightly identified the area within which an explanation was to be found; whether or not the teacher could provide a more detailed explanation is unknown. The teacher may have had the everyday idea that the substance itself is called condensation, but if prompted could have correctly identified the stuff as water. She may or may not have understood condensation as a process, as the change of state from water as a gas to water as a liquid.

There may have been a lack of conceptual understanding here, but there may not. The only misunderstanding may have been about the nature of the explanation which was expected.

2 *I Why does it seem to be behind the mirror?*
T It's refraction.

The teacher identified the area in which she thought the explanation was to be found, but she was mistaken. Reflection and refraction were confused. It may well be that in further discussion the teacher would have revealed more understanding of refraction and then realised she was using the wrong concept; or it may be that there was no more understanding of refraction to be revealed.

Two things have to be distinguished; understanding of the adequacy or inadequacy of the label as an explanation and understanding of the ideas of which the label acts as a summary identifier.

Some other common examples from our discussions are as follows. Each of these was given as a response to a request for explanation; each should be thought of as preceded by 'It's just....'

Arm	Muscles, the brain, tendons, muscular action.
Carbon Dioxide	The greenhouse effect, pollution, combustion, the ozone layer
Mirror	Reflection, refraction
Water	Condensation, change of state, water vapour
Fish	Evolution, adaptation, natural selection, survival of the fittest
Circuit	Conductors, insulators, resistors

An inappropriate analogy is given.
If asked to explain something and an explanation is not immediately obvious, it is natural – and useful – to look to some related area and make use of understanding known to be appropriate in that area. Understanding is then transferred from one location to another; the transfer may well be appropriate and helpful or it may not. Giving an analogy is a recognised mode of explaining; deciding whether a particular example of it is valid is difficult. It depends on a scrutiny of the degree of correspondence between the two situations (what is the same and what is different) and on the characteristic features of the analogy used. There is a real danger also that what one person regards as inappropriate unhelpful or bizarre, another may regard as illuminating, valuable and creative.

Some examples of analogies which were judged to be inappropriate are given below.

Arm	Heart muscles push blood around the body; skeletal muscles can push bones.
	Weight training involves pushing weights; muscles can push.
	Solids, liquids and gases expand and exert forces; muscles expand and push.
Carbon Dioxide	The greenhouse effect is like holes in the ozone layer; because there are holes in it, more energy comes through and things get hotter underneath.
	Coal is a store for energy and carbon dioxide; the carbon dioxide is inside ready to come out.
Mirror	The reflection you see in a mirror is just like the same object standing behind transparent glass.
	The eye works like a camera; the light to see things comes from the flash.
Water	Gases have more energy than liquids; think of the energy given out when gas burns and explodes.

Fish	These fish are different because the environments are different; it's like a plaice lying on a chess board.
	Things become different through evolution – like the tadpole changing into a frog.
Circuit	Electricity flows through air; lightning does it and so do sparks from electricity cables.
	A battery is like a water tank; electricity empties out of it.

Some teachers gave us analogies we could not really judge as inappropriate; we could see that they might well have value in helping pupils to develop understanding. The fact that from a strictly scientific viewpoint they could be judged 'wrong' did not empty them of all pedagogical value.

A judgement of scientific respectability can itself be difficult. One teacher would help pupils to understand that liquids have more energy than solids, by pointing out how water when it freezes releases enough energy to burst water pipes. Is this relationship between micro-level molecular energy and macro-level mechanical energy sound? Is it helpful?

Attribution of properties that do not correspond with reality

In many explanations, properties were ascribed to substances and objects that they just don't have. This category of misunderstanding is the only one in which it is usually easy to make the judgement: 'that is wrong'. Examples occurred in five of the six topics; we give just two examples from each.

Arm	Muscles push outwards. Tendons pull on bones.
Carbon Dioxide	Glass attracts heat. Fossil fuels contain carbon dioxide.
Mirror	Our eyes send out light. Reflected images have a spatial location.
Water	Water moves through metals. Water, as a gas, burns.
Circuit	Metals are insulators. Heat is visible.

A mechanism is proposed for which there is no evidence

In this type of misunderstanding, the teacher described a substance, a device, or a sequence of events which, if true, would account for the result observed. There is however, no evidence that any of these actually exist or occur. We were struck on several occasions by the ingenuity of these proposals and often they seemed to us to have value as hypotheses which should be discussed or tested. (The search for evidence would frequently, but not always, be beyond primary pupils.) In other words if these mechanisms were suggested by pupils they should not be summarily dismissed but kept 'on hold' as ideas which might later be considered.

Arm	The forearm can move back outwards when the muscle that pulled it in relaxes; this is because there is a spring-like device in the elbow.
Carbon Dioxide	Carbon dioxide in the atmosphere stops the cold getting in. The earth itself breathes out carbon dioxide.

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Mirror	Our eyes send out light which illuminates the things we see. The mirror illuminates the back of the reflected object.
Water	When two different temperatures mix, they produce cloudiness. There is a substance mid-way between liquid water and water as a gas.
Fish	When an animal moves into a new environment it changes and then that change is passed on. Animals change their structure so it is easier for them to feed.
Circuit	The bulb doesn't light because the parts of the circuit were joined up in the wrong order (in time). The current comes out of one side of the battery and then is used up as it goes round the circuit.

It should be noted that there can be overlap between categories; for example, one teacher said that 'water moves through metals' (attribution of properties not corresponding to reality), another said 'the water inside the tin moves through the walls of the can and appears on the outside' (proposal of a mechanism for which there is no evidence).

Equating everyday language with scientific language.

There is a great deal that could be said on this topic. Before dealing with the misunderstanding indicated by the title, it may be helpful to comment briefly on the **understandings** regularly shown by our teachers about the importance of language in teaching. Many seemed keenly aware that the development of conceptual understanding within science could be seen as essentially a matter of language development; they would have agreed with Sutton (1992) that teaching science is crucially an induction of learners into a language community – involving the creation and re-creation of meanings. Several teachers stressed that one had to start from whatever meanings were already possessed by pupils and then develop other meanings. Some teachers identified scientific terms to which they themselves could attach no meaning with confidence; in other cases awareness was shown of instances where the scientific meaning was known and recognised to be different from the colloquial or everyday meaning .

However, there were examples where assumptions were made that a familiar everyday usage was the same as a scientific usage; in these cases there was lack of any awareness that a problem (or teaching opportunity) existed. A few examples are listed below.

Term	Everyday usage	Scientific usage
Muscle	Part of the body which bulges	A special type of tissue
Cold	A thing which positively exists	Relative absence of heat energy
Burning	On fire	Combination with oxygen, releasing energy
Reflection	Observable object	Image perceived
Condensation	The wet stuff	The process of a change of state
Survival of fittest	Survival of strongest	Selection of the best adapted
Battery	Source of current	Source of energy

Some means all

This type of misunderstanding was infrequent. It occurred when teachers, understanding that some feature was usually true made the assumption that it was always true. One might expect to find this misunderstanding: it is common in young children and may well be a characteristic and necessary feature of all intellectual growth. Concepts are formed with the recognition of the general applicability of a categorisation and then later refined by the recognition of non-examples.

One of our teachers, knowing that some gases burn, made the leap to asserting that all gases burn: a characteristic feature of coal-gas was assumed to hold for all gases including water vapour. Several teachers were well aware that putting heat energy into something usually raised its temperature and then assumed that it always did so; this then inhibited their understanding of why heat was necessary to change ice at 0° Celsius to liquid water at the same temperature.

Scientific explanation is unnecessary?

There were a handful of instances where teachers appeared to jump from a scientific way of thinking into a quite different one. This was most common in dealing with evolution (FISH) where some teachers just said 'God designed it that way' and 'That's just Nature's way'. It is unclear to us whether these were rejections of a scientific mode of explaining things or indications that no scientific explanations were available. We felt almost that teachers were saying to us that there was really nothing there to be explained.

■ The 'understandability' of the eighteen big science ideas

In reporting on the six science topics, we mentioned at various times the numbers of teachers displaying and developing understanding. Such figures are all gathered together in tables 4.12 and 4.13.

These tables show the numbers of teachers who, in the judgement of the researchers, either

(a) showed understanding of the idea without any prompting or assistance (+ +)

(b) developed understanding by the end of the discussion (or revealed understanding they originally claimed not to have possessed) (– +)

(c) showed no evidence of understanding the idea (– –)

or

(d) provided insufficient evidence for a valid inference of understanding to be made. (NE)

An additional category (+ –) was necessary only when we looked at teachers' *own* perceptions of their understanding: 'I thought I understood that, but now I realise I didn't'. In a very few cases it was necessary to make use of the (NE) category; there was usually sufficient evidence within the discussions for researchers to be confident in their judgements.

Table 4.12: *Numbers of teachers showing understanding of different ideas, by topic. Group A teachers [N=28]*

		Arm			Carbon Dioxide			Mirror		
		Science ideas			*Science ideas*			*Science ideas*		
		1	2	3	1	2	3	1	2	3
a. Understanding shown without prompting	(+ +)	18	5	6	4	9	1	10	15	0
b. Understanding developed, or revealed, by end of discussion	(– +)	10	22	21	16	16	8	18	9	7
c. Understanding not shown at any time	(– –)	0	1	1	8	3	16	0	4	20
d. Insufficient evidence available	(NE)	0	0	0	0	0	3	0	0	1

Table 4.13: *Numbers of teachers showing understanding of different ideas, by topic. Group B teachers [N=27]*

		Water			Fish			Circuit		
		Science ideas			*Science ideas*			*Science ideas*		
		1	2	3	1	2	3	1	2	3
a. Understanding shown without prompting	(+ +)	10	22	2	27	3	4	20	17	4
b. Understanding developed, or revealed, by end of discussion	(– +)	17	4	16	0	15	6	6	9	14
c. Understanding not shown at any time	(– –)	0	0	9	0	8	17	1	1	6
d. Insufficient evidence available	(NE)	0	1	0	0	1	0	0	0	3

The obvious comment on the figures in these tables is that it is impossible to answer the question: 'How good is teachers' understanding of the science in these topics?' Everything depends on what ideas are to be included within a topic. Each one of our six topics can be made easy to understand – or difficult to understand – depending on what ideas are defined as being involved. There is some rough general sense in which 'Arm' can be said to be better understood than 'Carbon Dioxide'; but it would be simple to make 'Arm' very difficult by introducing some idea about the structure of muscle fibres; 'Carbon Dioxide' could be made easier to understand by leaving out the requirement to explain how the greenhouse effect comes about (idea 3). It thus makes little sense to talk about the level of teachers' understanding of *topics*; there is more point in considering teachers' understanding of the individual ideas that we claim underpin each topic.

We calculated three different indicators of understanding (IU), each based on the number of teachers showing understanding of an idea at different times. These indicators can be thought of as measures of the likelihood of an idea being understood by our teachers, ie the 'understandability' of the idea.

1 IU:PRE This indicator is given by the total number of ++ judgements for an idea divided by the total number of judgements of understanding for that idea. It indicates the understanding possessed by teachers before the discussion in our interviews.

2 IU:POST This is the total number of ++ judgements, plus the number of – + judgements, divided by the total number of judgements of understanding for the idea. It indicates the understanding possessed before *and* developed/revealed during discussion, ie the teacher understanding at the end of the discussions.

3 IU:(POST-PRE) This gives an estimate of the amount of understanding apparently developed by participation in the discussion. One might claim it allows a crude prediction of the ease with which teacher understanding of that idea can be developed.

Table 4.14 shows the understandability of the eighteen ideas. This rating was derived principally from IU:POST indicators, but the IU:PRE indicators were used to distinguish cases in which IU:POST values were identical.

The table invites some speculation about the reasons for the ordering of the items. The ones at the top seem to be closely related to observables and to have an everyday familiarity; this may stem from those parts of basic secondary school science which are most memorable or most likely to be reinforced by the normal experiences of everyday life. The ones at the bottom more often introduce abstract concepts, like energy; they tend to depend on the understanding of a greater number of prerequisite concepts – as in numbers 15, 16 and 17 – or to pose particular problems for effective communication (No 18). The ideas associated with the greenhouse effect are quite difficult in their own right, largely because of the subordinate concepts involved, but perhaps also because the ideas are confusible with those underpinning the related topic of ozone layer depletion.

It is interesting to note that there is no easy separation in the table between biological and physical science ideas; one might have predicted that primary teachers would have found the former more understandable than the latter. The relative difficulty of some biology ideas is influenced by the evolution ideas; these are sometimes thought to be relatively understandable – on our evidence, they are not.

Table 4.14 was based on end-of-discussion understanding. We also looked for a way of analysis which would make some use of all three understandability indicators. We first separated out those ideas with an IU:PRE of over 0.6; this is roughly the same as saying that over 60% of our teachers understood these ideas at the start of the interview. These ideas are in Group A below. We then divided the remainder into those with a high IU (POST-PRE) – again over 0.6 – and those with a low IU (POST-PRE) ie less than 0.6. The former group (B) contains ideas which were less commonly understood at the beginning, but in which understanding was quite readily developed or revealed during the discussion. The latter group (C) contains ideas which were less commonly understood and in which understanding appeared relatively slow or difficult to develop. The 0.6 dividing line is an arbitrary one; a different choice would produce a different allocation of ideas to groups than in Table 4.15.

Table 4.14: *'Understandability' of the eighteen big science ideas*
(ranked on end-of-discussion understanding)

Most frequently understood idea	1	The differences observed are helpful in the different environments in which the fish live.
	2	Bones move at a joint because of muscles.
	3	Water (as a gas) in the air changes to a liquid when it meets a cold surface.
	4	To see an object, light from it has to enter the eye.
	5	Water can exist as solid, liquid or gas.
	6	For an electric current to flow, there has to be a circuit of materials, each of which allows electricity to flow quite easily.
	7	Switches make (complete) and break the circuit.
	8	Muscles have to be in pairs to reverse a movement.
	9	Muscles pull; they do not push.
	10	Carbon dioxide in the atmosphere acts like the glass in a greenhouse; the temperature is higher (things get hotter) 'inside.'
	11	To see a reflection, light from the object bounces off the surface of the mirror before reaching the eye.
	12	Carbon dioxide is produced when fossil fuels are burned.
	13	The battery supplies electrical energy which the bulb changes to light/heat energy.
	14	There are chance differences within a generation that can be transmitted to the next generation.
	15	Gas changes to liquid when heat/energy is taken out; solid changes to liquid when heat/energy is put in.
	16	Evolution occurs over a period of time, because of the selection of those inherited differences which are helpful for survival.
	17	It is easier for light energy from the sun to get in through the carbon dioxide/glass than it is for heat energy to get out again.
Least frequently understood idea	18	The brain 'assumes' that light has followed a single straight line (from behind the mirror), even if it has been reflected on the way.

Table 4.15: *Three groups of science ideas*

Group A	*Ideas commonly understood by teachers at the beginning of the discussions (High 'PRE')*	
	Differences in fish are helpful where they live.	(Fish)
	Water exists as solid, liquid, gas.	(Water)
	Current flow needs circuit of suitable materials.	(Circuit)
	Switch makes and breaks the circuit.	(Circuit)
	Bones move at joints because of muscles.	(Arm)
Group B	*Ideas less commonly understood at the beginning, but in which understanding was readily developed. (Low 'PRE' – big change)*	
	Muscles pull; they don't push.	(Arm)
	Muscles are in pairs to reverse movement.	(Arm)
	To see an object, light has to enter eye.	(Mirror)
	Water (as gas) from air condenses on cool surface.	(Water)
	Energy in or out for change of state.	(Water)
Group C	*Ideas less commonly understood and in which understanding was relatively difficult to develop. (Low 'PRE' – small change)*	
	Greenhouse effect – gets hotter inside greenhouse/atmosphere.	(Carbon dioxide)
	Carbon dioxide from the burning of fossil fuels.	(Carbon dioxide)
	Chance variations inherited by next generation.	(Fish)
	Energy from battery changed by bulb to light/heat.	(Circuit)
	Light bounces off mirror to give reflection.	(Mirror)
	Easier for energy to get in than back out again.	(Carbon dioxide)
	Image appears behind mirror – brain assumes no reflection of light.	(Mirror
	Natural selection of helpful variations leads to evolution.	(Fish)

This grouping of the ideas has, we would argue, some value in predicting the type and extent of inservice support that is desirable if teacher understanding of different science ideas is to be enhanced. We take up this point in Chapter 6.

It may be that the understandability of ideas like these would be better appreciated if we could see their place within some pictorial representation of the substantive structure of the relevant part(s) of science. This would be a useful activity for future research.

How does the level of teacher understanding vary?

The range of teacher understanding, of the nine big science ideas over three topics, is great. This is easily seen by looking at two teachers: the one with apparently greatest understanding and the one with least.

Teacher X	Number of ideas understood without any prompts or assistance	7
	Number of ideas where understanding was shown by end of discussion	2
	Number of ideas not understood	0
	Number of misconceptions revealed	0

Teacher Y	Number of ideas understood without any prompts or assistance	0
	Number of ideas where understanding was shown by end of discussion	4
	Number of ideas not understood	5
	Number of misconceptions revealed	6

We took the analysis further by calculating for each of the 55 teachers a 'POST' index of level of understanding (by adding the ++ to – + scores for each teacher across the nine big ideas relevant to each). We then selected from the A teachers and the B teachers the top nine and the bottom nine with respect to their level of understanding; where the POST index did not provide a precise discrimination we then took PRE into account, making an assumption that the level of understanding is higher when not produced after discussion. We thus had from our 55 teachers a top third of 18 teachers and a bottom third. We then looked at the length of experience and the amount of science background for each of these teachers and found how many of each of the top and bottom thirds had more or less experience and some or no science background.

Table 4.16: *The experience and science background of teachers in the top and bottom thirds with respect to understanding*

	Top third N=18		**Bottom third** N=18		**% in Phase 2** N=55	**% in Phase 1** N=514
Experience						
12 years or more	12	(67%)	13	(72%)	70	65
Less than 12 years	6	(33%)	5	(28%)	30	35
Science background						
Some	10	(56%)	0	(0%)	33	39
None	8	(44%)	18	(100%)	67	61

1 The top 18 and the bottom 18 are not significantly different with respect to length of teaching experience – and not significantly different from the Phase 2 teachers as a whole.

2 Those in the top third with respect to science understanding are more likely to have some science in their background than not; there is no-one in the bottom third who has some science in their background.

3 Eight of 18 in the top third for science understanding have no science in their background.

We also looked at those teachers who had only biology in their background; not surprisingly their understanding of biological ideas (as in ARM and FISH) was better than their understanding of physical science ideas.

Understanding of these science ideas is on the whole better amongst those teachers who have science in their own background; there is nothing very surprising about this. Perhaps more interesting is that there were teachers with science in their background who were in the middle third for level of understanding

and that there were teachers with no science who were in the top third. There is a negative side to this: *some* science in a primary teacher's background has not guaranteed that they have a good understanding of the science ideas they are now expected to develop in pupils. There is also a positive side: some teachers without any science in their own schooling have, by their own efforts or with assistance, gained adequate or good understanding of those ideas that are to be developed in pupils.

■ What can we say about teachers' understanding of science?

Phase 2 discussions with teachers covered six topics/events. Each of these was derived from one of the foci of study or key features or bullet points in pages 16–21 of the *5–14 Environmental Studies Guidelines*: contexts and contents for developing understanding of science. Two topics were chosen for each attainment outcome, four for the P4–P6 stage and two for P7/S2, two on which teacher confidence about their understanding was high and four on which it was low. The six topics are varied and provide a sample which reflects the totality in reasonable ways. However, there are 42 content and context statements for science for P4–P6 and 54 for P7–S2; these vary enormously in generality/specificity and thus in the number of topics such as ours which would be necessary to cover all the implications of each. Suppose we were to discount the P7–S2 stage and say it remains problematic as to how much of this should be within the understanding of primary teachers and say also that our P4–P6 topics, although not covering all of any one content and context statement, actually contribute to the concepts involved in several, then we might claim that our four topics for P4–P6 cover the science necessary for at most 10% of the P4–P6 science content.

As far as we know, no-one has as yet attempted to fillet out 'the big science ideas' that are desirable for explanations arising from observation of objects and events that could occur in 5–14 science. We do not know what the total number of such ideas might be, nor do we know what proportion of this total our 18 big ideas might be. A rough guess might be about 5%. Thus, although we have had a great deal to say about the understanding of 27 or 28 teachers within three topics and across nine big ideas, any generalisation of this to teachers as a whole, or to science 5–14 as a whole must necessarily be tentative.

Primary teachers already understand quite a good deal of science; this provides a foundation on which to build. There is much science that primary teachers do not understand; this makes the professional development of primary teachers to cope with the science in 5–14 a matter of considerable urgency.

Summary Points about Teachers' Understanding of Science

- It makes little sense to talk of teacher understanding of *topics*; the level of understanding depends on the ideas defined as necessary to understand that topic.
- The science ideas we looked at varied widely in their understandability. (One big idea was securely understood, with no assistance, by every teacher; another was understood by no teacher initially and by only seven out of 27 at the end of discussion.)
- Individual teachers varied widely in their level of understanding across the ideas. (One teacher clearly understood all the ideas at the end of the discussion – and most of them at the beginning; another revealed understanding of less than half of the ideas, even after collaboration with the interviewer.)
- Many teachers possessed misunderstandings of those ideas they are expected to develop in pupils.
- Development of understanding of some ideas took place rapidly during brief discussion; understanding of others developed much more slowly and/or less frequently during the time available.
- Having some science in their background made understanding of the big science ideas by teachers more likely, but did not guarantee it.
- There were some teachers with no science background who had managed to gain good understanding of the big science ideas.

4.3 ... about teachers' understanding of technology

Introduction

Fifty-five teachers discussed aspects of technology with us; the discussion focused on six topics; we called these ...

A1 Robotic Arm
A2 Chimneys
A3 Mirror Device
B1 Rain Gauge
B2 Fish Design
B3 Kettles

We aimed to discuss topics A1, A2 and A3 with group A teachers (28 in number) and topics B1, B2 and B3 with group B teachers (27 in number). Because of time constraints all three topics were not always covered with every teacher; the accounts which follow are based on discussions with, on average, twenty three teachers. (The order of topics was varied so that no one topic was consistently omitted.) It should be noted that each technology topic was discussed after a science topic to which it was related in a loose, thematic way; the link in the interview was scripted to make it clear that the move from science to technology did not imply that technology was to be seen simply as the application of science.

Our purpose in the technology discussions was more to uncover and throw light on the understandings possessed by teachers than to check whether they actually possessed the understanding we thought they 'ought' to possess. The discussions were less structured than in the science topics and the time spent on each topic was limited (about three–four minutes). Given these conditions any quasi-quantitative conclusions should be treated with caution; our descriptions should be seen as suggestive and illuminative rather than comprehensive and definitive.

Topic A1: Robotic Arm

Teacher confidence on this was low, with a confidence index of 194 – see page 41.

Relationship to guidelines

Technology Attainment Outcome:	Understanding and Using Technology in Society
Strand:	Knowledge and Understanding
Key Feature/Focus of Study:	Simple relationships between the way people control their movements and the way control technology helps us to produce automated systems to control the environment.
Stages:	P4 to P6

Robotic Arm

Teachers had talked in the first part of the interview about movement of the human arm (muscles, bones and joints). The interviewer then produced a picture from a book for young children showing a simple robotic arm and prompted the teachers to talk about its similarities to, and differences from, a human arm.

Without exception teachers studied the picture carefully and proceeded to talk fluently about similarities and differences. The rigid parts were identified as being analogous to bones and the robotic arm appeared to have 'joints' at 'shoulder', 'elbow' and 'wrist'. Teachers commented on the different types of movement they thought the robotic arm would be capable of, pointing out, for example, that it looked as if the wrist could rotate through 360 degrees. It wasn't obvious what kind of grip there was on the end of the arm: whatever it was, it was unlikely to be capable of the variety and precision of movements possible in the human hand. What was analogous in the robotic arm to muscles in the human arm could not readily be observed or inferred; teachers were well aware that there had to be something to exert appropriate forces to move the different bits of the arm: 'Perhaps it's those pipe-like things. What are they – pumps?'

Teachers did not confine themselves early in our talks to simple structural points. One commented on the limited range of the robotic arm, unless the 'body' to which it was attached could also move from one place to another; a second teacher pointed out that the robotic arm could go on repeating a particular action without boredom or fatigue.

The interviewer then picked up a pen from different places on the table and asked if a robotic arm could do the same thing. (This question is suggested by the example given in the Guidelines for this key feature 'eg how we use our senses to pick up an object and how a robot using control technology could pick up an object'.) Two teachers took the discussion no further, saying they just didn't know: 'I'm at the limit of my understanding'. Most teachers said there was no great difficulty: you get the robotic arm to pick up the pencil once and then 'you just programme it' to repeat the action.

One interaction is particularly interesting.

T. *You can just train it – programme it, I suppose – to pick up the pen again and again.*

I. *I picked up the pencil from here and then from over here.*

T. *Well, they can programme the robotic arm to pick it up from one place and then again from another place.*

I. *How does it know which place the pen is in?*

T. *There are very sophisticated robots that can be programmed to do lots of things – but they can't decide which thing they want to do; they can't think. They do what they're programmed to do; if you want something different you re-programme them.*

I. *Can a robotic arm tell where something is?*

T. *There is probably a computer saying which bit of the programme you use...*

I. The computer decides whether the pen is here or there …

T. … or a complicated task you always need someone, somewhere to operate it. You do need humans still; a computer isn't like a brain – not yet.

Leaving aside this teacher's admirable keenness to follow her line of thinking uninfluenced by the interviewer, this excerpt illustrates three things that were common in the discussions.

1 As we said above, 'it's programmed that way' was a frequent response and it may well be that it is a reasonable, indeed useful, response. Some of our teachers were reminding us that it was probably unnecessary to understand all the details as long as you had the general idea: 'you don't need to understand how it works, as long as you know what it can do'. Our teachers never said to us 'this is achieved by an appropriately designed piece of control technology'. (No doubt they could easily acquire this language usage were it required of them! The phrase conveys as much, or as little, as 'it's programmed that way'.)

2 Teachers very seldom talked about how the robotic arm could determine where the pen was. In only two cases did they mention any requirement that the robotic arm have some way of sensing or 'seeing'.

You and I can see where the pen actually is; the robotic arm can't see where it is …

The arm can't easily sense where the pen is.

The concept of a sensor interfacing with a computer appeared not to be possessed by any of our teachers.

3 Teachers were clear about the highly sophisticated behaviours of which robotic devices are now capable; they did use words like 'machine' and 'artificial intelligence'. They were, very reasonably, unsure of what exactly remained, or would continue to remain, as distinctive features of human intelligence. Creativity, adaptability and decision-making were the things most often mentioned as still needing a person somewhere behind the machine (and, they hoped, controlling it).

Computers can very easily make robots work like our limbs – but computers are not yet like our brains …

There were, as would be predicted, some teachers who showed considerable lack of confidence in handling the ideas and language of technology; however, there is no general impression from the discussions of this topic that teachers were keen to avoid teaching it.

I did quite a lot on this sort of thing at college – even although I had never done physics at school. I don't think it would be difficult to teach, if I was properly prepared and could tackle it through constructing things. I would need suitable resources …

I just need very clear directions about what to do... and what the pupils are expected to get out of it. Then I'll do it.

Several teachers made imaginative points about how they would approach the teaching (although we did not ask about this here).

> *And for a start I wouldn't use pictures like these. If you are studying movement, use moving pictures – like a video. And I would talk with pupils about what* ***they*** *think; I want to distinguish* ***real*** *technology from science fiction; this topic is much more important than getting robots to do the housework for you.*

> *I think I would like to treat it historically, developmentally. I can see a nice project here about how you lift things – help for your arms. Levers and shipyard cranes – and those modern pneumatic cranes; going on to fork-lift trucks and robotic arms....*

One teacher was so effervescent, we should like to quote her at some length.

> *I've done quite a lot with...what's it called – DACTA? It's a kind of Lego. We made things like dentists' chairs that could go up and down with pumps. But I've also done other technology, related to the computer. Computer-controlled-robotics – I've done it! I used LOGO – you know, controlling the duck. The pupils* ***loved*** *it. They found the best way to do it first, then programmed it. They had instruction cards and managed to understand the LOGO language. So I've got no problems, no fears; I've done it....!*

■ Topic A2: Chimneys

This feature was not included in the questionnaire; we do not, therefore, have a figure for teacher confidence.

Relationship to guidelines

Technology Attainment Outcome:	Understanding and Using Technology in Society
Strand:	Knowledge and Understanding
Key Feature/Focus of Study:	Control of the environment (eg the monitoring and control of flue gas emissions)
Stages:	P7 to S2

Chimneys

Teachers had just discussed the burning of fossil fuels, formation of carbon dioxide and the greenhouse effect; the talk was then focused on a picture of a coal-fired power station, with a little accompanying text, in a book for young pupils. The interviewer said: 'Let's leave these ideas and move on to a bit of technology. It looks from this picture as if there is a lot of polluting going on. Is looking at a power station good enough to check pollution levels?' A series of prompts that could be used as necessary. 'If this is not enough, what could you do?' 'There's a lot of steam coming out of the cooling towers; is that serious?' 'You can see smoke, but you can't see some things like carbon dioxide ... what is needed?'

The picture showed equal numbers of chimneys and cooling towers, each belching out similar-sized clouds, all of the same colour. This was not chosen as some kind of trap for our interviewees; we thought it raised legitimate issues and would prompt useful discussion of certain ideas – both in knowledge and pedagogy. This proved to be the case, and only one teacher showed some minor irritation at what she construed as a trick to confuse her.

About a third of the teachers (nine out of twenty-four) began by making some distinction between chimneys and cooling towers or by asking the interviewer which she should focus on; a further third came later to realise that this could be an important difference.

> *Those ones are cooling-towers; it's probably mostly steam coming out of those. If it's only water, it shouldn't do any harm.*

Just over half of all the teachers ended up answering the initial question in a way which showed clear understanding of the important underlying principle.

> *No, you can't tell if there is a lot of pollution just by looking at it; pollutants are not necessarily visible and visible things are not necessarily pollutants.*

> *No, you can't. I think pupils might well think that –and I would say to them, you may not be right. How could we be sure? That kind of questioning is part of science and technology.*

These teachers found it easy to follow this up by suggesting that you would need some kind of detecting device if you wanted to monitor how much carbon dioxide (or other 'nasty') was being emitted. Teachers were divided as to where the monitoring device would be: some volunteered that they thought it should be fitted inside the chimneys; others thought that the air should be sampled at various sites around the chimneys.

Most teachers worked out for themselves that such monitoring devices would be necessary; others had direct evidence from some personal experience.

> *We went on a visit to a local timber-plant; pupils thought that the steam was pollution and then the manager told them that all power stations and factories have to have pollution measuring meters fitted.*

> *I've seen a TV programme which showed gauges to collect and measure the different various gases being emitted..*

We didn't press for any further details about how such monitoring devices might work; this seemed to be inappropriately demanding. However, two teachers did go on to suggest ways that were somewhat unrealistic: measuring the carbon dioxide with a computer programme and studying the lichens growing nearby. The latter shows possession of relevant knowledge, but it is difficult to see how lichen growth could be used as a monitoring mechanism which would respond rapidly to fluctuations in a continuous emission.

Teachers identified three interesting misunderstandings that they felt pupils were likely to have and then admitted that in two of the cases they had had them themselves.

> *Children react first to the volume of smoke they see: the more smoke they see, the worse is the pollution.*

> *Children think that if it's black it's really bad; if it's white it's not so bad. I probably thought that myself because I didn't know until you told me that carbon dioxide was colourless and invisible.*

I used to think that you can smell some emissions and not others and the ones that you smell are pollutants; I'm sure the kids think that.

The conception of what is and is not a pollutant is itself intriguing. Some teachers were unsure as to whether carbon dioxide, being colourless, odourless and non-toxic, could reasonably be called a pollutant at all; others clearly believed that everything other than the primary product of a process should be described as polluting i.e. the idea of a harmless by-product was not one they possessed.

Although not specifically asked about issues involved in teaching a topic like this, teachers offered a number of useful points.

1 Pupils were said to be generally familiar with and interested in environmental problems and it was not difficult to capitalise on that interest. However, it was necessary for teachers to be aware that things they as teachers thought commonplace might well not be familiar to pupils – for example, smoking chimneys.

2 Teachers often mentioned the need to get out of the classroom in encouraging sensitivity to environmental issues. Among visits mentioned were coal and oil-fired power stations, nuclear power stations, local factories and rural air-testing stations.

3 The resources available from, for example, BP were praised.

4 Several teachers pointed out that most primary teachers were required to trust the authority of text-books in science and technology.

I assume, when I don't know myself, that the books must be right.

I trust the text book. That illustration there is deliberate (ie in showing similar emissions from chimneys and cooling towers) *to convince the pupils that power stations give out a lot of pollution.*

It should be noted that our discussions focused on **monitoring** pollutants entering the air from a coal-fired power station. The actual statement in the Guidelines is 'control of the environment eg the monitoring and control of flue gas emissions'. Within the discussions it was accepted by interviewer and teachers that monitoring would be carried out to discover if there was an unacceptable situation that should be remedied i.e. that monitoring came before control; we did not go on to discuss how that control would be carried out. This would require detailed knowledge of the composition of flue gas emissions and of physical, chemical and engineering procedures that would be effective in removing each constituent (or at least in reducing the concentration of it to acceptable levels) which it was not our intention to elicit.

■ Topic A3: Mirror Device

Teacher confidence on the main focus of this topic was low, with a confidence index of only 175 – see page 41.

Relationship to guidelines

Technology Attainment Outcome:	Understanding and Using the Design Process
Strand:	Knowledge and Understanding
Key Features/Focus of Study:	The different stages in the design process and strategies they can use within these stages
Stages:	P4 to P6

This topic also relates to 'the needs of particular groups in the local community from Understanding and Using Technology in Society' – P4 to P6.

Mirror Device

Teachers had just discussed with us how people see a reflected image (of a toy dinosaur) in a mirror. The interviewer then said: 'Let's leave that and think about a bit of design technology. Suppose you have an idea that your pupils might design something that would help senior citizens see the back of their heads, to help them do their hair. How would you get pupils to tackle this?' Follow-up questions by the interviewers were related to the statements in the Guidelines we referred to earlier 'What different stages might pupils go through in this process?' 'How should they decide whether the device is any good or not?' 'Would the senior citizens themselves be involved at all?'

Twenty-five teachers discussed this topic, which, without any doubt, was the technology topic on which teachers were happiest to talk at length. In all cases the teachers talked with assurance and insight and (in all but two cases) with apparent pleasure. For whatever reason, the topic engaged teachers' enthusiasm and gave them an opportunity to demonstrate the extent of their pedagogical understanding and expertise. The general impression remaining after immersion in all the data, is that most of our teachers have a basic understanding of the design process (although they would not normally call it that) and that it would not be difficult to build on and develop that understanding.

Most of the teachers (twenty-one) talked about the phases of teaching/learning they would plan for their pupils in ways which showed understanding of 'stages in the design process and strategies they (i.e. pupils) can use within these stages'. This does not mean that the teachers all produced similar accounts of some prevailing orthodoxy all expressed in predictable language. One teacher's reply can serve to illustrate many.

> *One, you've got to get the nature of the problem clear. I'd start from the senior citizens' real difficulty. Then I'd do a brainstorming session with the whole class to get ideas about what it should be like and we'd argue about the kinds of materials we might use. We'd select two or three designs that looked possible and maybe draw them and then I'd supply each group with a tray of materials; they'll bring in some things, but you can't rely on that alone. I'd try and leave them alone during the construction phase. We'd assess whatever was made – probably select the one that seemed best and then think how to improve it. Then we'd try it out in a real situation. This is a much more worthwhile idea than making something that is of no use whatsoever.*

All of the teachers, although sometimes in response to a gentle prompt, talked with confidence about relevant criteria for assessing materials and evaluating designs. These included weight, bulk, portability, fragility, safety, cost. One teacher was so enthused at this stage she went on to describe how she would get the best group to work to an extended design brief which would involve not only seeing the back of the head but brushing and combing the hair as well.

Only five of these teachers talked about a bit of their own teaching that they themselves called a design exercise. We learned about designing carrier bags, ways of getting things up and down a mine shaft, safe road crossings, bridges and rain water collectors. Two teachers had been on inservice courses about design technology, but had not yet mounted a design project with their classes. In other words, the majority of our teachers could talk with some understanding about design technology from their experience of class projects that they had not thought of as design or technology. The transfer of knowledge was not, of course, always perfect. One teacher, for example, saw the purpose of construction as to give a product that could be displayed rather than one which could be tested in use.

We have suggested that a small minority of teachers (four) did not show understanding of design. That is not to say that there was a complete absence of understanding, only that their ideas appeared in need of considerable development.

You just give them the materials and let them get on with it.

Design is just experimenting with different ways of doing things.

These four teachers still viewed the teaching of this kind of design exercise in a positive way. There were two teachers, however, who understood what it was all about – but had no enthusiasm for working this kind of thing into their own teaching.

I've never considered doing anything like that myself and I'm reluctant to contemplate it.

Reasons given for this lack of enthusiasm were: the construction aspect is very difficult to manage (one person) or dangerous (one person); the technology guidelines switch people off (two people); an inservice course given by people perceived as being hopelessly out of touch with 'real' children (one person).

The finding that the majority of teachers had a good understanding of teaching the design process, had either taught it successfully or viewed the prospect positively, does not mean that teachers thought such teaching was easy and unproblematic. Six interesting issues emerged; these all occurred as we discussed Mirror Device – but they are of general relevance to the teaching of design technology.

1 Involving the 'real' users

Not all teachers thought of involving the senior citizens in some way, but most reacted positively when it was suggested. Ways of achieving the involvement were varied. Obviously teachers were aware that sending a class of pupils to interview one or two senior citizens would be unwise However, two teachers said that there was a retirement home nearby and that a small group of pupils

wishing to visit and having a clear purpose would be warmly welcomed. Another teacher suggested inviting a couple of senior citizens into the school to discuss their needs with pupils at an early stage in the design and perhaps to come back 'to test the prototype later'. One teacher had a different approach.

> *Pupils have got to enter imaginatively into an understanding of the design problem; you could do this with the help of the old folk – but myself I'd approach this through role play and creative drama.*

2 Guidance of creativity

There were differing views amongst teachers on the priority they would give to stimulating children's imagination and on the ways it could best be stimulated and canalised.

> *Obviously you want ideas, but children are brilliant at coming up with daft ideas and with throwing together bits of junk to make things that can't possibly function.*

> *It's really difficult to get a balance between giving them room for creativity and giving them sensible constraints; they can waste an awful amount of time.*

The generation of ideas from pupils through brainstorming was not seen as difficult; what **was** difficult was to get pupils to settle to 'sensible' discussion. A few teachers identified this as a recurring problem in all problem-solving type activities and issued a plea for practical help with this aspect of class management.

Keeping pupil creativity within bounds was managed by some teachers through careful selection of the materials made available: they argued that you should not ask pupils to bring in everything that they might use – either they forget and bring nothing or else they produce a great heap of wildly unsuitable offerings.

> *I prepare the materials – in more quantity and variety than they need – and tell them they will get little else. They're then amazingly inventive **within** what I've provided.*

This careful provision of materials was seen as the most time-consuming aspect of design exercises.

3 Involvement with the concrete

The practical involvement with 'real' materials and objects was seen as a strong attraction of design technology. Teachers were unsure, however, as to just how soon the practical activities and materials should be introduced. Responsiveness to children's interests suggested it should be more or less at the beginning, but adherence to the standard model of the design process meant delaying the concrete until a range of abstract ideas had been dealt with. Using a construction kit and following a recipe meant pupils could start on the practical right away; a design exercise tended to postpone what pupils found most enjoyable.

> *I have difficulty in getting them to think, discuss and plan; they want to build things right away and then test them. They want to jump into the concrete...*

4 Pupil groupings

Teachers raised familiar issues of size and number of groups, whether all groups should do the same or different things and how all groups were to be effectively

supervised at once. In addition points were made about the composition of groups for design technology.

> *Design is ideal for mixed-ability groups, because quite often pupils of lower abilities have better ideas.*
> *Different pupils are good at technology compared with other subjects.*

The view that technology gives different pupils a chance to show their abilities was held by a few teachers and might merit further investigation. One teacher had an intriguing hypothesis that affected her allocation of pupils to groups and her subsequent management of them: the pupils with the best ideas in technology are *not* the best-liked pupils in the class, therefore good ideas from them tend to be pooh-poohed because of their source.

5 *The place of drawing*

Interestingly, a lot of teachers said that they felt that the production of drawings – ideas, plans, design features, prototypes, final products – ought to have a clear place within the design process, but they wanted advice on what that place should be. There seemed to be an appreciation that both creative doodling and precise diagrams might be involved; but whether drawing was a desirable adjunct or a necessary phase was wholly unclear.

> *I just don't know whether they are supposed to make a working drawing of the prototype. When and what do you draw? Does it come early on or later?*

6 *The timing of a knowledge input*

About a quarter of our teachers remarked that this could be a good 'project' to do after they had done a science topic about understanding what mirrors could do and how they worked; the sequence within the interview could have influenced their thinking. However, a few teachers said that the need for pupils to know and understand something might crop up within the project and that was then the best place to teach it – because pupils would realise the point of it. This is the classic dilemma posed by all project and theme-based teaching.

> *I wouldn't get into this via the science as you did; I'd start from 'needs' and then only do the science later if it seemed necessary.*

The last point leads to one final observation in this section. We could not help noticing how frequently teachers used the terminology of science when talking about technology. At times this seemed to verge on the inappropriate and unhelpful.

> *Designing is just the same as experimenting – it's an experiment with materials to try things out.*

However, one teacher used language which, although unusual, embodies a not unhelpful metaphor.

> *Getting the ideas for a model is like hypothesising. An imaginative design idea is a hypothesis to be tested by a construction.*

■ Topic B1: Rain Gauge

Teacher confidence on the main focus of this topic was low, with a confidence index of only 175 – see page 41.

Relationship to guidelines

Technology Attainment Outcome:	Understanding and Using the Design Process
Strand:	Knowledge and Understanding
Key Features/Foci of Study:	The different stages in the design process and strategies they can use within these stages. (P4–P6) Different criteria for evaluating the effectiveness of a design. (P7–S2)
Stages:	P4 to P6

The topic also relates to 'the merits/demerits of simple against sophisticated designs' from Understanding and Using Technology in Society. (P4 to P6)

Rain gauge

The science discussion with teachers had made use of a small, metal tin. The interview then asked: 'If you were doing some work on weather, how effective would this tin be as a simple rain gauge?' Follow-up questions included: 'What would you take into account in deciding how good it was?' and 'How could we improve on this design?'

Twenty-one teachers discussed this with us, most at some length. These B group teachers showed no less understanding of design process than did their A group colleagues, but they did appear to be less engaged by this topic and more easily distracted. (Perhaps Mirror Device appealed to teachers as responding to a genuine human need and having good educational potential, whereas Rain Gauge appeared rather 'ordinary' and unlikely to yield any great educational benefit.)

The majority of teachers talked with understanding about a range of factors which would be involved in an effective design: the size of the collecting vessel, where it would be located, stability, transparency, visibility of the measuring scale, corrosion, cost etc. They also had things to say about the merits and demerits of simple as opposed to sophisticated designs and of making your own gauge as against using a commercially available device.

Several teachers would not have considered teaching this as a design exercise. In two cases this was because they thought there was a **right** answer and they already knew what it was.

> *Oh, I know the answer to this one – you use a transparent plastic bottle and a filter funnel.*

In two other cases, teachers would just produce the commercial gauge that was available and perhaps discuss its suitability with pupils.

Two teachers who clearly did see this as an opportunity for some design technology had done a project on weather studies the previous session and had tackled exactly this design task. They had found it a useful and productive exercise. In addition to talking with understanding about stages within the design process and the strategies they would encourage pupils to adopt, they made other points stemming directly from their experience.

> *One pupil suggested it would be easier to measure a difference in levels – so we tried this. What I didn't appreciate in advance was the difficulty we would have over the units for measuring. We started off thinking about parts of an inch – so we could compare with newspaper reports – but I ended up having to teach them about millimetres.*

> *One group were keen on a complicated design which wouldn't let water other than rain in and which wouldn't let the water escape again after it was inside; we linked this with condensation and evaporation.*

As with other topics, some teachers were a bit surprised to realise that things they already do under some other title might be covered within technology Guidelines.

> *There's a lot I already do, then – except I call it a spade and they call it a shovel.*

Several teachers said (as they did in Mirror Device) that these aspects of technology did not involve any difficult **ideas**: the concept of a design process seemed to be quite straightforward and the point of the whole process was to get things to work well rather than to comprehend difficult ideas. It is thus intriguing to see what happened when teachers did realise that there was a difficult concept within this design challenge; no teachers raised this themselves and the problem was only opened up by the interviewer in half of the discussions. In these cases s/he asked: 'Does the collecting bit have to have the same cross-sectional area as the bit where you measure the depth?' There were three types of response.

(a) Non-recognition of the problem

> *No, I don't think so, although I haven't thought about it before.*

(b) Recognition of the problem: simple solution

> *Ah-ha.... I see. I had never thought of that before. You have to have the collecting bit the same area as the measuring bit for an inch to mean the same thing.*

(c) Recognition of problem: range of possible solutions

> *It doesn't have to be the same, as long as you know the ratio of the two. If your collecting thing was ten times bigger, then the water in the measuring bit would seem ten times deeper and it would be easier to measure.*

It is possible to have confidence in one's understanding and for that to be misplaced; it is also possible to lack confidence and for that lack to be unjustified. One teacher started by saying she was lost and that she hadn't a clue about how the gauge could be better designed. She went on to give an account of what she might do in her classroom which showed a secure understanding of many of the features of design technology suggested in the Guidelines.

In the course of our discussions about Rain Gauge teachers also made general pedagogical points like those we described earlier, but rather less frequently. They stressed the problem of *guiding* pupils' ideas, practical involvement, the acquisition and organisation of materials, pupil groupings and management problems posed and the knowledge-input timing.

■ Topic B2 Fish Design

This feature was not included in the questionnaire; we do not, therefore, have a figure for teacher confidence.

Relationship to guidelines

Technology Attainment Outcome:	Understanding and Using the Design Process
Strand:	Knowledge and Understanding
Key Features/Focus of Study:	Knowledge of a range of contexts within which the design process may be applied.
Stages:	P7 to S2

Fish Design

The science topic before this centred on observation of photographs of two very different kinds of fish and involved a discussion of how the difference might be explained by ideas about evolution. The interviewer then said: 'We have been talking about these big ideas in science. Let's move to something which might relate to technology. Could we say that this flounder is well-designed for its environment?' It was the intention that a useful discussion would ensue which would reveal teachers' understanding 'of a range of contexts in which the design process may be applied'. Our thinking was that such understanding would be shown by teachers' recognition that there were contexts in which the design process was inappropriate or of limited relevance. Although the topic seemed quite productive when piloted, it did not work well in the school interviews; our teachers saw little point in the question and the interviewers usually failed to generate much engagement of minds.

We did not anticipate that the discussion would follow any particular path. There were, however, two points that we thought that teachers might raise in one way or another.

(i) 'Well-designed for the environment' may well be used routinely as an alternative way of saying 'well-adapted to the environment', but in the context of thinking about evolution it is useful to distinguish the two.

(ii) 'Well-designed for the environment' suggests there has been some intentional application of a design process; this is justifiable if one believes there is a designer – God, the Creator.

In all except three cases, the discussion was very brief and consisted of little more than the confident pronouncement that the fish was indeed well-designed for the environment in which it lived. The following response is representative of many.

> *The camouflage in that fish and the streamlining of the other are both examples of fish being well-designed.*

One teacher argued that to claim a fish was well-designed did not necessarily mean that somewhere there was a good designer of fish, because the species could act as its own designer.

A second felt that both fish had been designed, but thought that the flounder was less well-designed than the other.

> *I don't think that the flat fish is a proper fish somehow– it seems unnatural; fish ought to be streamlined. The flat fish has survived, but without the same quality of life as the other one.*

A third neatly expressed the two points we anticipated.

> *Adapted to the environment doesn't mean the same as designed to suit it, unless there is a designer who has used the so-called design process. I am very happy to teach that God is the most skilful designer of all.*

■ Topic B3 Kettles

We did not use this feature in the questionnaire and thus cannot quote a confidence index.

Relationship to guidelines

Technology Attainment Outcome:	Understanding and Using Technology in Society
Strand:	Knowledge and Understanding
Key Features/Focus of Study:	Ways in which control technology can be used to provide various levels of control or automation.
Stages:	P7 to S2

Kettles

Before discussing this topic, teachers had talked with us about electrical circuits; this had included consideration of how a simple switch worked. The interviewer then said: 'Let's leave those science ideas and think about an aspect of technology that could be related. Have you got an automatic electric kettle at home? What does it do that earlier types of electric kettle could not do?' (We looked for some indication that when the water boils in an automatic kettle, the electrical energy supplied to the kettle is switched off.) After exploring this together, we asked 'Could a kettle be made to switch itself on again, to keep the water nearly boiling?' This discussion was related to the Guidelines statement: 'ways in which control technology can be used to provide various levels of control or automation ... eg electric kettle (open loop) and automatic electric kettle (closed loop)'.

The most obvious thing to report is that twenty three teachers out of twenty four had no problems at all with he basic ideas in this topic; they discussed things with confidence, assurance and apparent pleasure. (However, one teacher did say she had never thought about it before and didn't really want to spend time thinking about it now.) Teachers rapidly latched on to the difference between (a) an 'old-fashioned' kettle which a person switches on and then later switches off again and (b) an 'automatic' kettle which a person must switch on, but which can switch itself off when the water boils. Teachers were quite happy to see this as a

different level of control or automation. Saying that teachers latched on to this idea we think gives the right impression. Roughly half of the teachers said they had never thought of it before; however, as soon as they started to think about it, they came up with helpful answers and were quick to use the new form of words (about level of control) introduced by the interviewer. We decided not to introduce the ideas of open and closed loops and no teacher used the terms.

Although the concept of switching on and off was obviously familiar to the teachers and that of level of automation was rapidly grasped, this does not mean that teachers knew how the switching device worked.

> *Then when the water boils, the steam clicks something off....I am not clear whether it's just because of the temperature of the boiling water or whether the steam actually pushes the switch to 'off'.*

Several teachers introduced the word 'thermostat' at this stage. Again they were clear what a thermostat could do, but not necessarily how it did it.

> *It's a thermostat; it switches a thing off at a definite temperature. I'm trying to remember how it works; it's got something to do with having two metals which boil at different temperatures.*

When asked to think about a kettle which might switch itself on again, a few questioned the value of having such a thing before going on to consider how it might work. No teacher had any difficulty with the principles involved. Two immediately spotted situations where the idea already applied.

> *Then you'd have a thing like the urn in the staff-room. You can get boiling water from it any time of the day, but it's a damned nuisance if no-one remembers to switch it off at the end of the day.*

> *That would be like the thermostat switch on a central heating radiator – switching it off when the temperature went too high and switching it back on again when it got too cold.*

With both of these teachers (although there were different interviewers) there followed interesting discussions about the role of such switches in saving or wasting energy. Unless it was considered essential to have boiling water on hand at all times of the day, the level of automation was probably unjustifiably extravagant in terms of energy consumption; on the other hand, if a room had to be at a certain temperature whenever people were using it, a thermostat might save energy by not letting the temperature get too high. One teacher suggested that the answer was to be found in a higher level of automation i.e. to have a thermostat operating for defined periods only under the general control of a time switch.

Three teachers told us they were confident about the idea of a switch and the different things that switches could do because they had already discussed these things with pupils in different situations. Projects described to us were about building a Morse code transmitter, building a light-house (with hand-operated and automatic switches) and constructing traffic lights for a cross-roads.

It was very noticeable in this topic that teachers regularly said the ideas were all very straightforward: 'Is this really in the Guidelines?' When the entry in the

Guidelines was shown to teachers, it produced a fascinating set of responses.

I'm really horrified at what it says there.. that's really off-putting. If you have no technology background, you think it will remain incomprehensible forever.

The language is difficult; the ideas are not.

You mean I have been implementing the Guidelines, without ever knowing it?

What can we conclude about teachers' understanding of technology?

When we were dealing with teachers' understanding of *science* we were able to focus on what we called 'big science ideas'; we could justifiably call these key concepts within the knowledge base of science. We were not able to do this for technology. There is no clear and generally shared view about the nature of technology education in schools; the technology attainment outcomes in the 5–14 Guidelines derive from science, the social subjects, the design process, and everyday life; we felt justified in defining only a very modest purpose for this part of the research – 'to describe teacher understanding of some simple aspects of control technology and of the design process' (Chapter 2.2). This is a more limited purpose than that implied by the first of our research questions: 'To what extent do teachers understand the key features of the 5–14 Guidelines in technology?' Our work in this area is exploratory and any conclusions are tentative; they point out the need for more research. (See Implications, Chapter 7)

What understanding did teachers display in each of the technology discussions?

Robotic Arm. Most teachers had a good understanding of structural similarities between a human and a robotic arm; their understanding of the control of movements in response to some sensory input was weak. They were aware of the range and variety of functions that robotic devices can now perform; they regularly said that robots 'can just be programmed' without showing much understanding of what this might mean. Primary teachers also showed what might be called the intelligent lay-person's understanding that some functions were more likely to remain outwith robotic capability than others; they regularly mentioned 'flexibility' and 'decision-making'.

Chimneys. More than half of the teachers understood that some visible emissions (eg water droplets) are non-polluting and that some pollutants are invisible; the remainder had difficulty with this because some pre-requisite knowledge was missing. The teachers with understanding had no difficulty in understanding the need for some monitoring device capable of detecting and measuring specific polluting substances.

There was a wide variation, amongst our teachers, in the level of understanding of the concept of pollution itself. There were a number of common misunderstandings that teachers had, similar to those possessed by pupils.

Understanding the technology in this topic requires prior understanding of a number of science ideas. We limited the discussion to 'monitoring', believing that 'control' (of flue-gas emissions) could require understanding of a very demanding

range of scientific and engineering ideas. Even within these limits, it was clear that when the underpinning science was not known and understood then the technology could not be understood. For example, if you do not know that carbon dioxide is invisible, you cannot be said to understand the limitations of simple visual monitoring of the emissions from a chimney.

Mirror Device. Most of the teachers showed a clear understanding of stages in the design process and strategies that can be used within these stages, although they did not use the standard vocabulary of design. If you were to ask a primary teacher what it means to specify a design brief, for example, you might well get very blank looks; on the other hand if you were to observe teachers' current practice you would see examples of teachers helping pupils to specify a design brief – the activity is relatively familiar, even if the particular label is not.

The acquisition of understanding here is more akin to learning some new vocabulary than to conceptual development. 'Understanding the design process', although it occurs in the knowledge and understanding section of the technology guidelines seems rather nearer to 'understanding the processes of science' than it does to 'understanding the key ideas of the substantive structure ...'

Rain Gauge. Most of what has been said about Mirror Device also applies here; teachers have a reasonable understanding of the design process, although they may not use the conventional language of design.

There is, however, plenty of scope to deepen teacher understanding of design and make it more secure. Just three examples; for a few teachers the naive belief that there is a 'right' answer to a design challenge militated against creative teaching; many teachers were very unsure of where, if at all, drawing – creative doodling or carefully measured representations – entered into the design process; there is conceptual confusion about designing, experimenting and trial-and-error.

Teachers often told us that in technology the language may be difficult, but the ideas are not. However true this may be, there are ideas which crop up in design technology which *are* conceptually demanding; in these a lack of understanding of an idea can result in the production of design artefacts which cannot satisfy their prescribed function. For example, some of our teachers did not understand how the relative cross-sectional areas of collecting surface and measuring device would affect the meaningfulness of the measurement of 'depth' of rainfall.

Fish Design. Most of our teachers did not seem to understand that the application of the design process implied the existence of a designer. They tended to see 'designed *for* an environment' and 'adapted *to* an environment' as identical.

Understanding of the range of contexts within which it is appropriate to apply the design process needs to be developed by explicating those in which it is inappropriate; our teachers did not, on the whole, show any understanding of this.

Kettles. Almost all of our teachers understood clearly the function of switches in different types of kettles; although the purpose and effects of the switches, in

producing different levels of automation, was understood, this did not mean that teachers understood how such devices worked. In a few cases an understanding of switches had been enhanced by teaching some technology topic, in most cases basic understanding had been acquired through everyday use of common appliances.

The language of 'control technology' was unfamiliar; the basic ideas to which it was applied was, in this case, familiar.

■ Comment

A significant proportion of teachers did not have a secure understanding of certain ideas in science; quite often they possessed misunderstandings as we reported in the previous section (4.2). When technology involves the application of these ideas, then the application will be misconceived or flawed. When technology involved the use of the vocabulary of design and control teachers were often unable to do this, although the ideas to which the language referred were understood. When technology involved understandings dependent on the 'common-sense of everyday experience', these understandings were frequently shown to exist; however, the life-experience of primary teachers is just as varied as that of other intelligent lay people and that kind of understanding cannot be guaranteed.

Teachers were pleased when technological activities they arranged for their classes resulted in enjoyable and engaging involvement; there is evidence that practical engagement was often seen as sufficient and also evidence that teachers were unsure as to the kind and frequency of the interventions by them that would enhance pupils' development of technological understanding. However, the confidence generated in teachers by their seeing they could organise productive technology sessions may well be valuable in itself; increased experience might well lead to increased concern that activity develops beyond more practical engagement.

There are serious questions to be posed. To what extent is an understanding of how technological devices work necessary to the successful and confident use of such devices? What understandings are expected of pupils as they progressively gain in technological capability? What is 'an appropriate base of technological concepts' for pupils? What understandings are desirable in teachers if they are to develop the conceptual base pupils need for technological capability? These seem to us questions that we, and others, have hardly begun to answer. We take consideration of them a little further in Chapter 6.

Summary Points about Teachers' Understanding of Technology

- Teachers were often unclear about the nature and purposes of technology education in the primary school.
- When teachers did not have a secure understanding of ideas in science, then the application of those ideas in technology was flawed.
- The ideas of control technology and design technology were often familiar to teachers, even when the terminology was not.
- Teachers often possessed those understandings of technology dependent on 'the common-sense of everyday experience'.
- Teachers tended to be satisfied with technology as enjoyable practical experience and underestimate its importance as the means for developing ideas.
- The Environmental Studies guidelines made technology *look* difficult; the technology we discussed with teachers was seen as simpler than expected.

4.4 ... about classroom practice

■ The science and technology taught

The following table lists the topics, themes or activities covered by the 33 teachers who took part in Phase 3 teachers between January 1994 and the time of the telephone interviews (usually March/April).

Explanatory notes

(a) For each teacher, an indication of science background is given. 'None' means no qualification in science from secondary school; 'Bio only' means a school qualification in biology alone; 'Science' means qualifications in at least two sciences at school.

(b) 'd/c' in a technology entry means this was reported to us as a 'design and construct' exercise (ie 'using the design process').

(c) An asterisk indicates that the topic/activity benefited from the presence of an outside expert; in most of the examples occurring here, this was a country park ranger.

Table 4.17: *Science and technology taught in Phase 3*

TEACHER (science background)	SCIENCE	TECHNOLOGY (d/c= designing and constructing)
01 (None)	Fish	
02 (None)	*Nature reserve	
03 (Bio only)	Space (5 weeks) – the moon (diary); sun and earth; the solar system; day and night; seasons.	Spacecraft propulsion. (1 lesson)
04 (Bio only)		Construction – designing shoe-box house; models of huts, wigwams, etc; construction of modern houses; bricklaying and cement mixing.
05 (None)	Oil slicks (4 experiments) – detergents; porosity; buoyancy; marbling	Woodwork – making a picture-frame; designing a swing.
06 (None		Oil-rigs (from newspaper) – shape (maths); structural strength (Eiffel Tower, etc); oil-rigs. (*d/c) Propelled boats (from junk) (d/c).
07 (None)	Electricity (6 weeks) – electrons, neutrons, batteries; *generation: reservoirs, turbines, pylons; circuits and switches; conductors and insulators; galvanometers.	
08 (Bio only)	Energy (6 sessions) – heat, thermometers, heat loss, insulation, electricity.	Electricity kit used to devise pinball machine, football stadium, basketball court, etc.

TEACHER (science background)	SCIENCE	TECHNOLOGY (d/c= designing and constructing)
09 (None)	• Water experiments – sinking and floating; surface tension; pressure; evaporation and condensation. • Fair testing: traffic surveys, temperature surveys. • Fitness – muscles, the pulse. • Music – sounds from containers.	
10 (None)	The body – pulse; eye; bones and muscles; smoking.	
11 (None)	*River life	
12 (None)	Space – galaxy, sun, moon.	Making moon-buggies and space-shuttles.
13 (None)		Flight – aero-dynamic shape, wind resistance; making helicopters, hovercrafts, rockets (with paper, corks, balloons, washers).
14 (Bio only)		Structural strength – testing tunnel shapes.
15 (None)		Making a climbing figure. Making a bird on the wing.
16 (None)	*Freshwater sampling (river purification)	Eiffel Tower (from paper spills).
17 (None)	Various, following TV science series, including food (and colouring), flight, weather.	
18 (Science)	*Insects – pond-dipping, food chain, conservation.	
19 (Science)	Various, following science pack: health (skeleton+muscles), environment (planting, growing seeds, recycled compost), changing states of matter (baking, plaster castes), electricity (circuits, switches and alarms.	
20 (Science)		The design process, based on TV series; d/c scaffolding for A3-size house (string, Sellotape, etc).
21 (None)	Electricity – lighting a bulb, making a bulb holder; electrons, protons; static electricity.	
22 (Science)	Energy (7 experiments) – autogiros, circuits, magnets, parachutes, vehicles, water clocks, heat transferance.	
23 (Not known)	As 22	
24 (Science)	Electricity	

TEACHER (science background)	SCIENCE	TECHNOLOGY (d/c= designing and constructing)
25 (Not known)	The body and the environment (climate, pollution)	
26 (None)		Flight – making whirlybirds.
27 (Science)	Density – mixing syrup, oil and water. Sound (vibration) – 10 experiments.	Vehicle to carry/pull load (d/c). 6 ft tenement (d/c).
28 (Science)	Friction – dragging a load over various surfaces (4 activities) Belts and pulleys (3 activities)	Friction – ball bearings.
29 (Science)	Electricity – series and parallel circuits	Electricity – making streetlights.
30 (None)	Light and electricity – lighting a bulb; insulators, conductors, switches, fuses.	Light and electricity – making a game with lights.
31 (Science)	The eye. The body.	Activities with commercial pack. Viking ship with hoistable sails (2 hours x 5 weeks).
32 (None)	Magnetism (5 lessons) – sorting metals; testing magnetic fields; poles, attraction and repulsion; floating magnets; centres of gravity.	Magnetism – making a balancing clown. Submarines (from plastic bottles).
33 (Science)	Cold water chemistry (3 experiments) – litmus to vinegar and water; distinguishing colourless liquids by litmus; chemical reactions.	Cut and fold model tank.

■ Why did teachers choose these topics/activities?

About half of the teachers (17) chose science and technology work which linked in to wider environmental studies topics (for example, Homes, World War II, Space Exploration, the European Community, Health Living, the Vikings, Oil, Rivers).

In other cases the science and technology topics were self-contained with titles like Energy, Electricity, Magnetism, Cold-water Chemistry, Water, Vehicles; these topics varied in scope from, for example, Energy (six sessions) to Designing a Swing (one lesson). The reasons for selecting self-contained science and technology topics usually seemed to come from personal and chance factors, rather than any broader school planning. Teacher 32 explained that she chose Magnetism because she had been on an inservice course about Energy and Forces, she had found a teacher-friendly book to help her, and she knew that the school had all the necessary equipment.

Two teachers offered a miscellany of activities from the biological and physical sciences, one based on a pack, the other on a television series. One of the two explained that she tended to cover science independently, as it could be difficult to integrate into topics. This point had been raised by another teacher in Phase 2, who felt that teachers had a tendency for 'getting trapped into the project, and

thinking if the science doesn't fit somehow into a theme, don't do it', and that this restricted the possibilities for covering science and technology. While another teacher agreed that integrating science into a broader topic was not always easy or possible, she also felt that covering it separately in upper school demanded more confidence.

One teacher said that she had decided on a science topic because she was aware of having neglected that area in her previous year (with the same class); electricity, she thought, would be enjoyable for the children. Two colleagues had been specifically asked by management to undertake a science topic following our Phase 2 interviews in the school.

No claim is made here for the representativeness of the teacher sample or the lesson sample. It is interesting to note, however, in view of what we know about teachers' overall preference for the biological rather than the physical sciences, that less than a quarter of our teachers covered biological topics. (The time of year may well have had a strong influence.) Similarly, although it may not entirely surprise us to find that the teachers who covered 'energy' and cold water chemistry had some qualification in physical sciences, the general impression given here is that the kind of science being taught by teachers did not seem to be much influenced by the science they had in their own background.

There are two aspects of the teaching summarised in Table 4.17 which are a little surprising. Firstly, although some teachers have clearly developed links between science and technology, there are many opportunities for such links that seem not to have been taken. Secondly, with the obvious exception of work by teacher 33, there is very little in this list that could be regarded as a foundation for later work in chemistry; this is odd, given that teachers' confidence in relation to Earth and Space is not particularly low. It would be a pity if the perception that chemistry needs fancy apparatus and expensive consumables to pour down the sink were to deter teachers from the useful and interesting work that can be done.

■ Difficulties encountered by teachers

Six possible sources of difficulty were identified on the pro-forma we gave to teachers; these were suggested by themes which had emerged unprompted in the Phase 2 interviews regarding the difficulties associated with teaching science and technology. There was space too for any other factors which teachers might wish to consider.

The six areas suggested were:

(a) preparation time
(b) equipment/materials
(c) subject content
(d) pupil difficulties
(e) classroom size or facilities
(f) class management.

The incidence of identification of each factor as a cause of difficulty is shown in the table below. Complaints relating specifically to technology are shown in italics; complaints relating to science are in plain type. Also included, in the last column, is each teacher's satisfaction rating, ranging from 'very happy' (1) to

'very unhappy' (4). This was given in answer to the first question on the pro-forma: 'In general how happy were you with this bit of teaching?'

Table 4.18: *Sources of difficulty and satisfaction ratings*

Teacher	Sources of Difficulty						Satisfaction with teaching			
							Science		Technology	
01			c				2			
02							1			
03	a	b		d	*e*		2			
04		*b*							1	
05			*c*	d		*ff*	1.5		2	
06			*c*	*d*					1	2
07	a	b	c			f	2		2	
08				*d*		f	1		1	
09							1			
10		b	c	d			2			
11							1			
12		b	c				2		1	
13	*a*	*b*		*d*		*f*			2	
14			c	d					2	
15		*b*	*c*						1	3
16					*e*				1	
17		b					2		2	
18							1		1	
19		b		d			1			
20		b		*d*	*e*	*f*			2	
21							2			
22	a	b		d		f	1			
23		b					1			
24						f	1			
25		b		d		f	2			
26			*c*	*d*					2	
27		*b*		d			1		2	
28		b	c				2	4		
29	a	b		d			2		2	
30	a	b		d	e		3			
31	a	b	c			f	2	1	3	1
32	a	b		d			2		2	
33		b		d	e	f	1		2	
Total mentions	8	20	11	17	5	10				

Each of the six sources of difficulty will be examined in turn; there then follows some comment on the satisfaction ratings.

a. Preparation time

The thing I find very off-putting about doing a science or technology lesson is first of all gathering the stuff, and organising it.

Several teachers in Phase 2 had complained, like the quoted example, of the time taken up preparing for science or technology lessons, and this aspect was identified as significantly problematic by 8 teachers in Phase 3. In the majority of cases (including the same teacher quoted) this was linked to the difficulty in finding good materials and reliable equipment. One teacher spoke of 'scavenging for equipment', another of the time taken up visiting libraries, the resource centre and the local secondary school. The need to try out experiments at home, to ensure equipment was in working order (or to become familiarised with equipment bereft of any instructions), also intruded into teachers' free time, as did designing suitably differentiated worksheets. Such preparatory tasks had taken one teacher 'hours and hours', and as her colleague pointed out, 'all that time and effort just for one-and-a-half hours a week!' She could only envisage attempting one 'big topic' a year, in part because of the amount of preparation involved but also because of the time taken up in the classroom. This worry that science or technology was eating into other areas of the curriculum was echoed by two other teachers.

b. Equipment and materials

This was the most frequently cited source of problems. Typical complaints were that

- equipment was unreliable, insufficient, difficult to obtain, or that it lacked the necessary instructions
- written materials were likewise not easily available, insufficiently differentiated, and too thin on background knowledge and lacking any indication of what might go wrong, why, and what to do about it.

The effect of these deficiencies was not only to make preparation much more time-consuming, but also in some cases

- to limit the teacher's initial choice of topic and activities
- to prevent further development of a topic when it was clear that the initial activities were not challenging enough for the children
- to render an activity almost pointless, as when pupils had to use paper to make skeletal models because no wood was available
- in the case of malfunctioning equipment (eg demagnetised magnets, unreliable pulleys, faulty circuits), to disappoint the children and even discourage the teacher from attempting anything 'complicated' in the future
- to restrict the children's active involvement (one teacher had to abandon any hope of group work and simply demonstrate an experiment, because of faulty equipment).

Two teachers were particularly unhappy with their technology materials: both the commercial kits and the activities books contained insufficient information and guidance for the teacher. Another stressed the need for a wide variety of equipment and ideas in technology, because children tended to view related incremental tasks as mere repetition ('We did that last week!'): building a bogey, a cart or a house with the same materials was all seen as 'the same thing'.

c. Subject content

Lack of background knowledge of the topic they were attempting to teach was felt as a problem by about a third of our interviewees. The unanimous complaint was that the teacher did not have the necessary knowledge and understanding to answer children's questions or resolve the situation when equipment broke down or experiments failed. It was clear that the teachers' concern was not primarily loss of face (no teacher reported embarrassment at having to tell the children 'I don't know'), but their incapability of furthering the children's understanding and the frustration and disappointment which often accompanied such impasses. One teacher reported.

> *I could help with basic problems, but when a boat didn't work when I thought it would, I didn't have the technical knowledge to help them improve.*

Another teacher (for whom science or technology was 'always a case of the children knowing more than you') had found her initial demonstration of procedure for her flight activity unproblematic, but as soon as problems arose and explanation was needed she had found it 'a real struggle' and was forced to leave the children to their own devices. This also meant that she was unable successfully to monitor and probe the causes of pupils' problems. She admitted that the science she tended to choose needed only activities which required simple materials like paper, paper clips and elastic bands; even if more sophisticated equipment were available, she said, she would shy away from it. Interestingly, although she had chosen to tackle a flight activity, she claimed to avoid technology completely (remarking in an earlier interview that the technology hour 'never leads anywhere – the children construct whatever it is, and then it just gets dismantled').

One teacher explained that her lack of understanding of the technology activity she had set the children had not influenced her planning (and that in any case she was more concerned with the co-operative nature of the task than its conceptual content); it *had* nevertheless limited the help she could offer her pupils and had prevented her from planning a follow-up activity.

In most of these cases it seemed that the immediate problem as perceived by the teacher was not her lack of understanding per se but the fact that equipment and written materials failed to include sufficient (or any) content knowledge to advance her understanding, and that there was nobody at hand who could be called on to provide such knowledge. In other words, these teachers did not feel that they should be specialists, but that support should be available through fuller, more teacher-friendly materials or expert advice. (Of these teachers, four would have liked access to expert help and advice, four wished for better written materials (with fuller explanations of the science/technology content and differentiated worksheets), and two would have appreciated an extra adult actually in the classroom.)

Five teachers in addition to these 11 did mention their own lack of content knowledge, but had not found this at all problematic. 'I'm useless but I don't mind asking around' said one teacher who had sought help from both her headteacher and a colleague's husband. Two teachers had simply referred closely to books. Another, being 'not at all science-minded' had relied on a television series, and

noted appreciatively that the children had picked things up very quickly and at times had understood better than she did. And another had been happy to encourage her more able pupils to experiment at length with the electricity kit and find answers to their own questions.

d. Pupil difficulties

The high incidence of this factor is probably deceptive. Teachers reported on children's difficulties because this seemed to be expected of them, but it was clear that in many cases these difficulties had not posed any problem for the teacher at all; they were simply part of the learning process. More important were those cases where a teacher's lack of content knowledge prevented them from helping children resolve their difficulties. A positive outcome of this, noted by several teachers, was the additional impulse for children to co-operate in solving problems amongst themselves.

Certain types of problems were recurrent, however, and might fruitfully be seen as important in (though certainly not exclusive to) the learning of science in primary schools. These include difficulties with motor skills, social skills (co-operating, listening, accepting ideas from perceived low-ability pupils), persistence. Several teachers commented that their pupils found recording and evaluating troublesome: 'they love *doing* the experiments', explained one, but found 'reflecting, talking, expressing concepts much more difficult'. One teacher whose pupils had difficulty both understanding and articulating ideas involved in the design process was dissatisfied with the sudden block input of technical vocabulary to which the children had been subjected; because of their previous lack of exposure to science and technology in the primary school, she felt children did not have the opportunity to acquire the necessary vocabulary gradually. Other teachers, however, testified to the ease with which children had assimilated new terminology.

Some teachers seemed to be struggling to find ways to bring their pupils round to understanding. One said she had had trouble moving her pupils 'beyond a 'looks rubbish' kind of appraisal', when evaluating the solidity of structures they had made. This echoes another teacher's concern (expressed in her Phase 2 interview but referring to the same activity she reported on in Phase 3).

> *They do the experiment and then say what they discovered. And some of them, all they could comment on was what they* ***saw*** *happening with the two whirlybirds, but they have no idea why it happened. And so I* ***have*** *to either give them enormous clues, or simply tell them.*

Another teacher had earlier agreed that children did not ask enough questions, but recognised that it was part of the teacher's task to encourage and guide enquiry which could only be done 'if we knew the right questions to ask them, if teachers were trained in how to ask the correct questions'.

Three teachers commented on gender-specific difficulties encountered among their pupils. One reported that the girls in her class had initially shown a certain reticence: 'turning up their noses at the mention of science' and being keener to plant seeds. Having given it a try, however, they had become more enthusiastic. Another teacher had noticed that it was the boys in her top group who enthusiastically applied their knowledge of electric circuitry to devising flashing

pinball machines and floodlit stadia: 'It's not that the girls weren't encouraged!' she assured us.

e. Classroom size/facilities

Three teachers had already bemoaned in Phase 2 the lack of physical space, particularly in regard to technology, and not surprisingly this re-emerged as an issue in Phase 3. Classrooms were too small to allow for proper demonstrations or testing (eg of propulsion models); they lacked sufficient storage space or display areas, and one teacher spoke of the difficulty of tackling simple chemistry in a room with only one sink (in Phase 2 one teacher had no water supply in her room at all).

Lack of space had also prevented effective grouping in one class where the teacher's aim had been to monitor group dynamics; it was difficult to avoid duplication of ideas when groups were in too close proximity. Moreover science and technology activities tended to be a distraction for the rest of the class, making effective and safe class management more difficult.

f. Class management

Most teachers who commented on this aspect found that because of the practical nature of science/technology activities (often combined with the need for in-depth discussion) their attention had been monopolised by the science/technology group to the detriment of the rest of the class, or that in the case of whole-class activities they had been unable to give the children sufficient individual help. One teacher considered that she had not been 'of much use to the children as I was trying to run here, there and everywhere'. This teacher also attributed the almost exclusive attention she gave her technology group to a concern for safety (the children were handling woodwork tools) and to her own lack of confidence ('I had to keep thinking all the time'). Another teacher was unable to take her topic (flight) to its logical conclusion (testing model helicopters and rockets) because the lack of available cover precluded outdoor activities.

It is notable in this respect that when teachers were asked what help they would have liked, the biggest demand was not for expert help (nor even better materials) but simply for an 'extra pair of hands'.

■ Teacher satisfaction with their teaching of science and technology

The researchers' concern with possible areas of difficulty in the teaching of primary science and technology should not be allowed to obscure teachers' own feelings of satisfaction in their teaching. Teachers were asked on the pro-forma and by telephone 'how happy [they had been] with each bit of teaching' (generally interpreted as meaning a block of science/technology lessons). The four descriptors given the teachers were as follows:

1 very happy; 2 quite happy; 3 quite unhappy 4 very unhappy

Teachers' responses are given in the last column of Table 4.18 on page 123.

Twenty-five teachers gave 27 ratings of their science teaching; the average rating was 1.65 ('happy'). Nineteen teachers gave 22 ratings of their technology teaching; the average rating was 1.73 ('happy').

- Notwithstanding the problems they encountered, in the vast majority of cases teachers were satisfied overall with what they had achieved.
- We did not set out to measure teachers' competence in teaching science and technology, and none of our data allow us to attempt such an evaluation or to set teachers' own judgements against some measure of performance. Clearly, even the most dissatisfied of our teachers may be underestimating the success of their teaching; equally it may be that highly satisfied teachers with no problems to report were oblivious to difficulties in fact existing. (In one case the data do in fact suggest serious conceptual misunderstandings on the part of such a teacher, with obvious implications for her pupils' learning.)
- While some teachers were clearly concerned with the problems they encountered and felt their teaching had been impaired, others may well have measured their success in terms of how much they had achieved *in spite of* all the difficulties. One teacher commented that she was 'very happy to have achieved any science at all!' Several teachers seemed to take the children's enjoyment of the lessons as the principal measure of success.

Clearly, we cannot comment on the appropriateness of the ratings recorded without relating these to teachers' *aims* in the science and technology activities they undertook. If, for example, these aims were principally to develop children's process skills or social skills, problems deriving from deficient content knowledge might be seen as tangential (even if a little unfortunate) and would not necessarily be thought to detract from the successful attainment of the original aims.

In fact a third of the teachers to whom we spoke gave some indication of what had been their aims or objectives. Only two of these referred to the development of conceptual scientific understanding (although it may be that others took that for granted), and two to the design process. Six teachers mentioned the development of co-operative skills. Others spoke of recording, of perseverance, of safe handling and cleaning of equipment, of 'trial-and-error' procedures and fair testing. The emphasis on process-oriented objectives is not too surprising, in view not just of teachers' unease vis-à-vis their own conceptual understanding and their greater confidence (evidenced in our Phase 1 survey) in their ability to teach process skills, but also given the context in which these teachers have been trained and have practised, ie the orthodoxy of process-based science.

One teacher's principle aim in teaching science was to break down its mystique, to present it as fun and as 'an easy way to explain phenomena', rather than 'something for boffins in a lab'. Another was quite clear about what she wanted her pupils to derive from their experiments.

> *It's just handling apparatus and getting used to the idea: 'What happened?' 'Bubbles' 'Great' 'Do I have to write about this?' 'No, you've done it, that's it.' Doing it is enough. I didn't want to go into the chemistry, but to get the children to apply a test and see they can produce a reaction. The whys are irrelevant.*

Not so precise was the teacher who said her lesson had 'worked very well'; although she did not understand the principles governing the technological task covered, the children, she felt, had enjoyed it enormously. Another teacher explained that a technological activity she had tagged on to her science topic was

set rather like craftwork, 'for enjoyment really'.

It is clear that a variety of considerations and attitudes would influence teachers' assessment of their teaching of science and technology, and a possible interpretation of teachers' satisfaction ratings may be that some teachers are too easily satisfied. Yet if we are going to address the question of teachers' lack of confidence in the areas of science and technology, we must equally take account of the fact that when delivering specific science or technology programmes in their classroom, teachers seem to show an ability to cope and a confidence that they are doing a reasonable job.

Teachers may express a lack of confidence about the *prospect* of teaching science and technology, based on an awareness of shortcomings in their own knowledge and understanding; however, having done some teaching, having got over the major obstacle of actually getting involved, they feel pretty satisfied in *retrospect* that they taught well enough – they have some of the confidence of success and are then less likely to say 'I need more understanding'.

Summary Points

- All thirty-three teachers taught a fair amount of science and technology; often what they taught was based on personal decisions rather than part of a school plan.
- The major source of difficulties was equipment/materials; however, about one third of teachers said they had difficulty with subject content.
- Most teachers were satisfied with what they taught, but the criteria to judge this were not usually centred on conceptual development in pupils.

4.5 ... about help wanted by teachers

Introduction

In phase 1 of the project, there was an open-ended question in the questionnaire which asked teachers to indicate 'What help, if any, you need in relation to your understanding in science and technology and what form this might take.' In Phase 2 teachers were asked, when time allowed for this during the interviews, 'What help do primary teachers need to teach science and technology?' In Phase 3, teachers were asked to note 'what particular help it would have been useful to have at any time during the teaching' (of the science/technology lessons they were reporting on and that would be discussed in the telephone interviews).

In Phase 1, 344 of the 514 teachers (67%) gave us written information; in Phase 2, 45 of the 57 teachers (70%) gave us their views; in Phase 3, 30 of the 33 teachers (90%) told us about help that would have been useful. It should be noted that the majority (but not all) of the Phase 3 teachers had also taken part in Phase 2 and the majority (but not all) of the Phase 2 teachers had taken part in Phase 1. In the three phases the contexts and the research methods were different; the responses complemented each other rather than being either identical or contradictory. What was said to us in Phases 2 and 3 confirmed and elaborated what we had already been told in Phase 1.

The Phase 1 question asked about help needed *in relation to understanding*. In some cases it was clear that teachers were responding to a precise interpretation of the question asked, ie they specified how they wanted to be helped to increase their *understanding;* in other cases teachers explicitly rejected the idea that any difficulties were caused by their own knowledge/understanding – they went on to specify the help they wished with other things (like more equipment and storage space); however, in the majority of cases we were unclear whether the help requested was to develop understanding or not ('more inservice training' – but, to what purpose?). We decided that in Phases 2 and 3 teachers should have the chance to suggest whatever form of support came to mind, irrespective of its purpose – hence the briefer wording of the question. This has given us some difficulties in reporting findings. The next section deals generally with the types of help requested; we then focus more specifically on help in relation to the development of understanding.

The types of help wanted

Three hundred and forty four teachers made a total of 640 suggestions in Phase 1; these are categorised in the table below in descending order of frequency.

Table 4.19: *Help requested by teachers (N=344)*

Type of help	Number of requests
Inservice training	314
Print-based resources and materials	103
More time to think and prepare	49
More/better apparatus and equipment	47
School policy on what to teach, when	40
Specialist help; outside experts	34
School action (priority, co-ordination, support, storage)	30
Larger, differently-designed classrooms	22

More will be said about these requests under the five headings which follow; inservice training; resources, materials and equipment; time to think and prepare; school policies, actions and accommodation; specialist support.

Inservice Training

The Phase 1 requests for inservice training can be grouped as in the table below.

Table 4.20: *Requests for inservice training*

Type of request		Number of requests	
Inservice training, to increase understanding		85	
– of which,	in technology		34
	in physical science		30
	in information technology		17
	in biology		4
Inservice training, perhaps related to understanding		229	
– of which,	no further details		91
	practical, 'hands-on'		58
	stage-related		17
	series of meetings, not just one		16
	teaching skills/classroom management		15
	general 'philosophy' of 5–14		13
	record keeping, assessment		10
	must build confidence		5
	other		4

Of the total number of requests for inservice training, 85 (ie 27%) asked for help to develop understanding of the subject content. There were remarkably few requests for help to develop understanding of biological aspects of science; the majority were concerned either with technology (34 mentions) or aspects of

physical science (30 mentions). The remainder were concerned with information technology/computing.

In 91 cases, the request was simply for 'more inservice training', without further details. Other requests covered a range of aspects of content and methods of delivery. A regular specification was that the training should be of a practical, workshop nature. This came to the fore again in Phase 2 interviews, when almost half the teachers who asked for inservice support stressed that it should not be lecture-based but should offer 'hands-on' experience, based on the classroom context and allowing teachers to familiarise themselves with materials and the handling of equipment. There was a preference for inservice training that was clearly relevant to the stage in the school at which the teacher taught; this was usually allied to a conviction that there was so much that *might* be covered in science and technology that when time was limited it should not be spent on things that could not be immediately applied.

One-off sessions were thought to have limited value; teachers liked the idea of a series of inservice meetings, with time between them to implement and/or reflect.

> *The courses are never long enough to do what you want them to do. You can instill a bit of confidence, but really, what can anyone do with someone like me in five hours? One day's training – I can't say it's not beneficial, but it's short and sweet, it couldn't explore a weakness totally thoroughly.*

> *It's all very well giving a teacher books, but we've got millions of books and documents to look at already. Inservice would be good, so that you're actually* ***doing*** *the experiments, finding the difficulties. It shouldn't be a one-off, it shouldn't be voluntary or after-school – it has to be a regional thing for all schools and has to be so-many times a year.*

Some requests were for the development of teaching skills in science ('how best to introduce scientific experiments') or technology ('how not to waste time with designs that can't possibly work') or for more general classroom management ('I need to be shown how to keep the rest of the class gainfully occupied, while ensuring the groups doing practical work are doing it sensibly and safely.') Other requests were for inservice courses on the general 'philosophy' of 5–14 or on themes important not only in science/technology (for example, assessment and recording).

Five teachers in Phase 1 explicitly stated that the only requirement of inservice activity should be that it increase their confidence – with the implication that previous experience had shaken rather than enhanced it. Similar points were made in Phase 2 interviews.

> *I don't want to be tested when I go on these courses or made to feel awkward, like a child with a blank sheet of paper frightened to put the first mark down. I've been up to the college for courses many, many time, and I've come back soul-destroyed,. ...*

Another teacher complained in interview that she had been to an inservice course which she expected to be about classroom activities and it turned out to be about the development of content knowledge; this, she said, made her feel more anxious rather than less. A rather different view was expressed by a male teacher

in Phase 3; he himself was experienced in science and had quite a lot of science in his own background. Inservice training should be about confidence-building and it should explain to teachers 'just how simple science concepts really are' and allay teachers' fears by this approach. It rather seems that science concepts are simple when you are confident you possess them – and difficult when you are not.

In the interviews, teachers tended to say more than in Phase 1 about the *scale* of the inservice provision needed. The usual adjectives employed were 'massive', 'intensive', 'on-going'.

> *The profession needs massive inservice, a great big confidence-building exercise, perhaps concentrating on one small area of science, like electricity: 'Just do this science, P7 teachers, even if nothing else, just tackle this – follow these instructions 1–10 and then you'll have covered x science principles'. They should focus on organisation because that's the one aspect of any new thing that puts people off – That's all very well, but you've got fifteen adults – how am I supposed to cope with that in my classroom with thirty kids?' – I hear that time and time again. And all too often these courses don't give you the practical tips, the wee handy hints – 'How am I going to integrate this into my day, would it be all right if I did it at language time?' These courses have to be run by primary teachers with experience of science, not by scientists.*

However teachers also sounded a note of caution: inservice training would be of limited use unless the proper context for implementation existed back in the schools. There was little point in going out of schools for inservice training, if conditions and equipment in schools did not allow effective teaching on your return.

Print-based resources, materials and equipment

Of the teachers who indicated in Phase 1 what help they needed to improve their teaching of science and technology, 30% requested helpful print-based resources and learning materials. (A further 15% asked for more, or better, apparatus and materials.) Half of these asked for packs that would cover 'everything necessary', and another repeated demand (17 mentions) was for summary guidelines specifying clearly 'what I have to do and when'. In addition, 40 teachers looked to the formulation of school policies to clarify what should be taught and when (which topics, for example, would be covered in which stages) and help them 'get to grips with what I have to teach'.

Much of this was reiterated in our Phase 2 interviews and in the Phase 3 lesson discussions. Of 59 teachers who were asked what help they needed, 32 asked for printed materials; these might be 'teacher-friendly' packs on specific topics, with detailed notes, clear instructions and sufficient background knowledge, and suitably differentiated material for the children, whether booklets or worksheets. As in Phase 1, highly prescriptive guidance was a priority for many teachers: packs should not assume too much knowledge on the part of the teacher but be step-by-step 'idiot-proof' practical guides telling teachers exactly what to do and how:

> *I would like to be told exactly what to do. I can read the Ginn manual and understand it, but it doesn't say: 'Experiment 1: get this and this and that'. I have to have my cards telling me exactly 'I'm doing this, I'm doing that', because of my feelings about science. I have to be over-organised, because I'm* ***scared*** *of science, and of technology.*

> *If there was a pack on a science topic, we would all just read it through and do it next term, but there aren't many packs that you can just pick up and have everything there and you just go ahead and do it. ... I'd rather be given a pack to give you ideas first, and then you go ahead and implement it, a set of cards maybe, saying 'to further that you could try A, B, C'.*

Although such responses may not suggest the most imaginative or ambitious attitude to professional development, they are made in the context of the very recent emergence of the 5–14 guidelines for environmental studies, and of teachers' awareness of the apparent enormity of the task ahead in implementing the guidelines. As one teacher (who had been discussing the mechanical structure of the arm) put it:

> *There's no lack of resources for what I would teach in science just now, there are lots and lots of cards that would cover virtually everything, but looking at the 5–14 there are things in there that would have to be bought, or I think should be produced by the SOED. Like that model of the arm you've got there, it's very interesting, but you see, with the overworked teacher, I think all these things should be available and it should be suggested that this is what's used. Teachers* ***really*** *need help. They can't expect us to go and think up these, because we're* ***not*** *experts.*

Eight other interviewees expressed this need for support materials to supplement the guidelines: 'a teachers' guide to 5–14 with specific examples for each target' or even a comprehensive national scheme, 'a kind of science SPMG'. Such prescription was necessary not merely to help teachers but to ensure that children throughout the country received a broad base of science and technology experience irrespective of teachers' individual strengths and phobias.

> *The guidelines need to be translated into what I am actually going to do with the children. It's all to do with translating it – we just don't know what we would do with the children to achieve a strand.*

> *What we need is a series of well-designed textbooks and worksheets on every topic, like, say, 'forces', as a national initiative, and for teachers to get the opportunity for hands-on practice of the experiments, so that however much extra a teacher wanted to do, every child would still have covered specific areas in science.*

> *Teachers really, really need help. If they're going to bring that 5–14 environmental studies in, it has to be laid down for us much simpler, plus the background information. Not a textbook, but books on the subject, especially for teachers who are not very sure in science. It would also have to be set down as an ongoing thing, at the different stages, so that you have to teach a certain thing at a certain year, because it it's not been done the year before how can you play your part?*

> *I would like to know what my definite outcomes should be in each simple experiment, and to ensure that what's being done in P7 is carried forth.*

One teacher was very clear that detailed prescription was needed, but that this was not provided by the environmental studies document.

> *First thing, this book should be thrown out. It's very intimidating and not that specific, it doesn't tell you very much. Separate it all out. Teachers like step-by-step guides – you know: tell me on the Monday I'm doing this, on the Tuesday I'm doing that. That would be much more appreciated. Give us a syllabus, basically, then give us a science kit, because we don't have time to go and learn a whole new subject, to go away and figure out levers and pulleys.*

One respondent stressed that any working party producing such back-up material must include practising primary teachers; indeed one confident senior teacher suspected that

> *a class teacher would do it better [than a science expert]. If somebody was to pay me to sit down and write a science pack, I'm sure I could.*

Only a co-ordinated consultative process, said another, could adequately produce the materials needed to meet the new curricular demands.

> *Commercial packs obviously have their place, and some are very good. But everybody has to work together on those things – there's not a lot of point in one company coming up with their particular approach to one topic. The people and companies producing the materials have to work with what the government wants and what teachers find credible and workable in the limits within which they are working. It can't be done in isolation, there has got to be a lot of discussion.*

When it came to discussing the science or technology activities teachers had actually undertaken in the classroom, the recurrent complaint about materials (apart from the lack of them) was that the commercial packs assumed too much knowledge on the part of teachers: they did not specify in sufficient detail what equipment or other resources were required, and they gave insufficient background knowledge. As one teacher put it:

> *They don't tell you what might go wrong, why it could go wrong, or what to do about it if anything does go wrong.*

The technology book she had used, 'typically', provided no introduction for the teacher and no coherent progression in the miscellaneous activities it prescribed. One teacher who was herself enthusiastic and confident about technology made the same criticism.

> *Half the time the books that look good, when it comes down to basics, they let you down – and it's amazing how many of them **are** wrong. It's highlighted in design-and-technology where it's just books with a wide variety of activities (maybe because it's still a new subject), whereas in science you would normally have a little bit of explanations to begin with and then build it up.*

Another teacher complained that the brand new electricity kit she had used contained no instructions; what she would have liked was a pack combining good equipment and clear instruction cards. That was what another teacher required also, before she would dream of tackling electric circuits in the classroom:

I wouldn't give them that because I don't know the first thing about it. I would avoid it, unless I was given a pack and it was all a logical progression and all explained to me first. Yes, if I was given a large box with teachers' notes I would read through it and use it. But I wouldn't go and buy batteries and bits of wire one day and say 'Let's see what we can do with this, children'.

Most of the comments on equipment were to the effect that it was either unavailable in sufficient quantity or unreliable, and a fifth of teachers interviewed over Phases 2 and 3 requested increased resourcing in this aspect. Demands were for:

- better (ie fully functioning) equipment
- sufficient quantity of equipment to enable maximum participation by pupils
- more appropriate child-oriented equipment (one teacher had had to use full-size bricks in a bricklaying activity, another complained of over-diminutive pulleys)
- advice on appropriate equipment, to counter misleading information in commercial catalogues.

It was essential, thought one teacher, that the provision of materials and equipment be linked to inservice training: if training was not immediately followed up with availability of materials in schools then the initial impetus and gain in confidence would evaporate; equally, without a confidence-building inservice programme, equipment, no matter how good, would still intimidate teachers and be left to gather dust in school cupboards. This echoed the views of another teacher who felt that, given the money, 'a lot of headteachers would be happy to resource it if the staff had the ability to use it'. And another thought provision of resources was of little value without a co-ordinated policy:

I wouldn't want money to be spent on science until there's a definite policy. There's no point putting money into equipment if no-one's prepared to use it. I think it's putting the cart before the horse to say 'Here's some science equipment; use it!'

A number of teachers identified the problem as being not so much one of insufficient resources, but lack of maintenance of existing resources.

Resources are a problem. For example we don't have enough batteries – or we do, but they're all dud. Classic example the other week: I took the magnets (we've got millions of magnets in school) and they were all dud, because they hadn't been put away properly.

For some teachers the answer was to have a school technician, to ensure equipment was kept in proper working order and also to relieve teachers of the burden of setting up equipment.

Science teachers at the secondary school have technicians who set up the experiments, tidy up afterwards, go and get things, whereas we have to do everything – we have to research it, set it up, do the experiment – and we're not experts, whereas secondary teachers are.

Several teachers identified the secondary sector as a source of equipment and advice, and hoped that better liaison with their associated secondary school would lead to easier access to specialist facilities and a sharing of resources.

Time to think and prepare

In Phase 1, 49 teachers, when asked what help they needed, said that they wanted *time* – time to 'get my head around the 5–14 guidelines', time to research the topics about to be taught and time to prepare pupil learning materials, equipment and apparatus. This request was also frequently made in Phases 2 and 3, when we were sometimes able to probe the thinking behind the request.

There is a cynical view in some quarters that whenever teachers feel they are being asked to do something additional or different they say (a) give me more time and (b) give me more resources; these are sometimes seen as automatic responses, not the result of thinking but a way of avoiding it. This may have been the case in a minority of cases here, but it was very far from being generally true. Our teachers seemed to be telling us that they had a degree of confidence in their general teaching ability and that they expected they would be competent, or develop competence, in teaching science and technology if they had time to think about what they were doing and to prepare it in a way that satisfied them. Present conditions did not encourage them to think that time would ever be available. In the majority of cases where this request was made it was not a request for help to be provided by someone else, but an assertion that the teachers were able to help themselves.

School policies, accommodation

There was a clear recognition by a number of teachers (40) in Phase 1, that the implementation of the science/technology guidelines seemed a huge and forbidding task when you read through the booklet, but that the task for individual teachers would seem much more manageable if and when each school developed a clear plan for what topics should be covered at what time and for how long within each school year. When a teacher looked, alone, at the totality of the guidelines, things seemed quite impossible; if, however, she and her colleagues got together and planned clearly what was to be covered by whom then the tasks in prospect seemed smaller – and one recognised one was part of a team.

Teachers mentioned other things that should be done within their schools to help them, although some things that were suggested might be difficult to arrange at the level of the individual school. These suggestions included

- a greater priority attached to science and technology by the headteacher and senior colleagues
- the appointment of one member of staff to act as lead-person, or co-ordinator in the science/technology areas
- the provision of technicians and other auxiliary support
- reorganisation of storage of resources to make them more accessible
- the creation of a science/technology activity base within the school
- the provision of more space, sinks and display space.

The number of teachers who said during interview that their classrooms were not such as to allow the easy management of safe, practical activity was considerable. Some argued for the setting-aside of special science/technology areas within the school; one felt that appropriate accommodation should be supplied in one centre to meet the needs of a cluster of schools.

Some of our teachers had already shown considerable ingenuity in creating, with management help, specialised activity and display areas in a previously under-utilised space. Of course, if science and technology could not easily be managed within the classroom, but took place elsewhere, this posed additional problems of supervision.

All of the teachers we interviewed were in relatively large schools – and they had at least six or seven colleagues. The teaching of science and technology in small schools will raise special problems; the teacher in a single-teacher school, for example, will have to come to grips with the totality of the 5–14 guidelines. There seems to be no answer for her in breaking things down into manageable chunks, parcelled out to a group of co-operating staff.

Specialist support

In Phase 1, 10% of the teachers who requested help had expressed, unprompted, the desire for support from external experts such as a visiting adviser or secondary specialist. This issue was probed further in Phase 2, when 39 teachers were specifically asked if they perceived a need for specialist help in the classroom. Two teachers were quite happy for science and technology to be handed lock, stock and barrel to a visiting specialist experienced in primary teaching; another welcomed specialist input into training during PAT training; but the majority were keen for a specialist to come into their classrooms on a sustained basis and teach science or technology (or in one case IT) while they themselves looked on; once the class teacher had acquired sufficient confidence, she would then dispense with the specialist but hope to have some form of back-up support available.

> *What I would like is somebody to show me what to do, to let me see how it's done and to give me ideas on how I can approach it with the children. I would be wanting somebody to guide me and put me on the right tracks, to give me ideas and I'll work from there, someone who I could then go to and say 'Look, I'm stuck, I got this far, where do I go now?'.*

Models for this were readily available to some teachers from their experience of visiting arts specialists.

> *I would like help, to have somebody come along, yes, that would be very helpful. You learn a lot about organisation as well as content from the art specialists.*

> *I think the best thing really would be to have a specialist come in, the way we have a music specialist. I'm not very good at music at all, but I've learned a lot listening to the lessons that the music specialist gives here. Seeing someone doing the science with the children and explaining it to them. Over and above that, have the background for the teachers as well – you would need both: to have the background knowledge for the teacher and then let the teacher see it put into operation by someone who knew exactly what they were doing.*

> *Oh, a visiting specialist would be wonderful! Even just to reassure you that you're going along the right road – because that's the problem, you don't always know that what you're doing is the right thing. Initially when this quality-of-life education started up we were to do PE, at which we all threw up our hands in horror and said 'How awful!' because we more or less tried to do the minimum PE, and I was really green, I had no idea about basketball, volleyball, netball, hockey – all those things we were supposed to do. But we had a* ***lot*** *of input, the specialist came from the High School and we were in with them, and gradually we didn't need the specialist nearly so much, and we had so much more confidence because we'd had this help. Something along those lines would be more valuable than throwing hundreds of books in.* ***Show*** *me* ***how*** *to do it.*

Several teachers stressed that such support must not become a 'cop-out for class teachers', encouraging them to ignore science or technology in their own teaching, but should be sustained till the teacher felt confident – this might mean the time taken to cover a full topic, with the teacher then applying the teaching methods and ideas she had observed to other scientific areas, or perhaps it might mean a much more sustained input: one teacher remembered the isolated 6-week specialist support block she had witnessed on placement as 'a complete waste of time and money', because of the absence of any follow-up support. She suggested such post-specialist ongoing support might best be provided by the associated secondary school.

A few teachers, although attracted by the idea of a visiting specialist, considered it 'dreamland' financially unless their regional authorities decided to give science and technology a much higher priority than at present. Some teachers, however, pointed out that specialist help could be provided by in-house experts, existing members of staff who had some knowledge of or particular enthusiasm for science or technology. As one put it:

> *In primary school, 'specialist' tends to mean somebody who knows a wee bit more than you do about it, so there* ***will*** *be somebody on the staff who can be the science specialist.*

Such an in-school specialist's role might be to provide her colleagues with ideas for activities and advice on materials; or to set up a science resource room and conduct PAT training, as one of our interviewees had done; or to take responsibility for all the teaching in those areas. Two teachers thought it was perhaps time for upper primary teachers to abandon their generalist status and specialise in particular subjects.

> *I can't be good at ten different subjects. I can be a kind of all-rounder and I can do* ***some*** *things for everything, but I would be much better at teaching only one or two subjects. See if I could come in every day and teach mathematics all day, or a wee bit of science to every class, I would* ***love*** *it.*

> *It did say in the [5–14 Environmental Studies] working paper about upper primary becoming not like secondary but having teachers teach specific subjects. I think that's what we have to move towards. I know I have my strengths, but I also have my weaknesses. And surely getting to your full potential at things you're good at is much better for the children.*

One teacher, who was extremely loathe to give up any aspects of her generalist remit, identified another source of expertise from which teachers could learn:

> *I certainly wouldn't want a specialist taking over – I like dabbling, that's why I came into primary teaching. But I'd love to spend a couple of weeks with a 4th year student nowadays doing her thesis on technology. That would be my ideal answer – an opportunity to work with one of these bright young things who's really into this in a big way, and to help them for a week, to see the ideas in action in a real practical classroom-type situation with other groups going at the same time, and I think once you'd seen it working and how it can take off, then you can think 'Yes, I can do that'.*

And indeed expertise could be found close at hand outwith the teaching profession.

> *Whenever we find a parent who does have more expertise than us, then we use them, I'm a great believer in using anybody you can.*

When it came to reporting back in Phase 3 on lessons they had taught, five teachers mentioned the valuable help they had received from various experts (countryside rangers, a Hydroboard representative, an oil industry worker participating in the Trainees In Primary School scheme, and local secondary specialists); three teachers would have welcomed some expert assistance, either vocational (eg a professional bricklayer) or from specialist teachers or through an advice hotline. Much more pronounced, however, in the context of actual classroom activities was the need for 'an extra pair of hands', whether staff or parent, specialist or not. Fourteen teachers mentioned the difficulty in effectively managing the class during a science or technology lesson without auxiliary help. As one teacher had already put it in her Phase 2 interview:

> *If they are going to be taught effectively they need to be taught in small groups. In practice you never get an uninterrupted period of teaching, so you need someone there to take the group or to take the class while you take the group – it depends how well I knew the area of science I was trying to tackle, obviously I want my children to get the best.*

Help in developing understanding

To what extent was the help requested by teachers seen by them as necessary to develop their understanding of concepts in science and technology? As explained earlier our data do not allow us to answer this question with assurance.

Eighty-five out of 314 Phase 1 requests for inservice training were quite explicitly about help to develop understanding; many of the 229 other requests *may* have had something indirectly to do with the development of understanding, we cannot be sure how many were like this. Similarly the requests for printed materials, for whole-school policies, for more time and for specialist support may well have been related to ways of developing understanding, but we do not know exactly how often this was so.

In the Phase 2 interviews, 16 teachers expressly linked their requests for action to the development of their own understanding of concepts; they asked for inservice courses which would address their lack of scientific knowledge, packs which would contain sufficient explanations for the teacher rather than mere descriptions of the activities, and some asked for time to 'get to grips' with the environmental studies document and its component subjects. We cannot deduce from this, however, that the many demands for prescriptive materials or hands-on, illustrative inservice specifically excluded the need for development of

conceptual understanding. Some teachers, it is true, complained that their initial teacher training had concentrated too much on the imparting of adult content knowledge rather than on teaching methods.

> *I felt that science at college was more an extension of the science we'd done at school rather than how to go about teaching it.*

But in many cases the repeated demand to be shown '*how* to do it' may well have contained an unexpressed need for some degree of development of content knowledge. The majority of teachers did refer at some time in the course of their interviews to their own level of understanding and the effect this had on their ability to teach science or technology, and this perception would presumably influence the kind of support they asked for. Only one teacher could see no problem whatsoever: although she had no background in science or technology, she did not find these any more difficult to teach than other areas of the curriculum and did not see the need for further support; teachers should simply 'get on with it and try things out'. Other teachers, without being quite so dismissive, felt that any gaps in their scientific education were not hindering their teaching. As most of them explained, they would first of all research a topic and make sure they understood it well enough before teaching it; this was an accepted part of their job, and the importance of being well prepared and well organised was not specific to science or technology.

> *I'd have to go right back, which is what I always have to do when I'm teaching something new, go back and research it, the whole paranoid bit: I have to take reams of stuff home and get stuck in there, and then find ways of presenting it to the children.*

> *Before I would do anything like this, I would go and do a lot of reading up and research. I don't ever try and teach science off the top of my head. There's very few things I teach off the top of my head, because I always feel I need a bit more background knowledge. It does mean a lot of scanning through books.*

For such research one teacher preferred to turn to children's materials; this approach, it would appear, gave her a better indication of what level of understanding would suffice to teach effectively.

> *There are children's books in the school that deal with science parts of the curriculum, and that's where I would start. If it's something I know absolutely nothing about, I start off from the children's books and work from there till I reach a point where I think 'Well I've probably got enough knowledge to deal with anything they ask me', and I stop at that point.*

Five of these teachers stressed the importance of being able to admit their not knowing to the children and motivate them to find out for themselves or with the teacher. 'Difficult' questions from pupils should not cause anxiety but provide an opportunity for learning together.

> *I wouldn't give them an answer I wasn't 100% sure of. I would always direct them to a book, and quite possibly go with them. We don't have to know everything – I think a lot of the time we're learning alongside the children, I ask them for* ***their*** *opinions more often than not.*

> *I'm quite happy to say 'Sorry, I don't know the answer to that question, where can we go and find out?'. I don't pretend to be a know-all. You've got to be positive and say 'Right, let's go from this not-knowing situation to finding out; let's do it together'.*

For two teachers such situations were opportunities for the children to realise that people had different levels of expertise and understanding, and that in some matters 'expert opinion' should simply be accepted. As one explained:

> *If somebody said to me 'why?' there, I would just die. I would find this [greenhouse gases, heat and light energy] really difficult to describe because I don't understand it fully myself, although I know it's a fact and I accept the experts' opinions and ideas, and I would have to be as open as that with my class and tell them that I didn't fully understand this because I'm not science-trained, and that they would have to take my word for it, as I do the experts'. I think it's a good thing for the children to know 'Teacher doesn't know, but she'll find the information'. I don't feel there's any need to be hung-up about that.*

A much higher number of teachers, however, made it clear that they saw their lack of scientific or technological knowledge as more problematic. One teacher who was worried by the demands of the 5–14 environmental studies document at levels D and E explained:

> *That book takes no account of the limitations of the non-scientific teacher. Earth and weather are pretty straightforward, I'm at least half-a-dozen jumps ahead of them, but the physics and chemistry in that document, and the technology section, are beyond my limitations totally. I've got to be two jumps ahead of the children cognitively and feel equipped and competent in assisting them with their activities. They've got to think that teacher knows better and knows all of it.*

This teacher's difficulties would be addressed by highly prescriptive materials ('provided I was given the tools and the results, virtually'), and sufficiently prescriptive specialist advice, but for several teachers mere prescription was not enough.

> *I would not be happy just to follow a manual that tells me what to do. You need to understand it to be able to teach it, you need to be ready to answer the things they might ask you, and it might not be just what you're showing them. If you're doing something wrong, you need to know that you've done it wrong and how to put it right.*
>
> *If it's something you're not familiar with, and you don't feel you have enough background knowledge yourself, and you're dependent on reading teachers' manuals, it can be quite frightening.*
>
> *Nobody's ever taught me how to teach science, it's all from manuals. We teach from manuals because it tells us 'This is how you to it', but sometimes teachers will teach and don't have a great understanding, and then that's a problem when those children who **are** science-minded or really interested come and ask questions, because teachers maybe really don't know. What I'm saying is, 'If people have not been trained in science, how on earth can they teach it?'*

The last teacher did ask for highly prescriptive materials ('to be told exactly what to do') and for inservice training which would train her 'in how to ask the right questions', but equally she was quite willing to see a specialist teacher completely take over the science and technology curriculum in her place. Her anxiety over the

possibility that she might be stumped by children's questions was shared by not a few teachers. For one at least, teaching science was like opening a Pandora's box ('once you start opening up science, they want to know so many things') another, who admitted that 'the very word science makes my heart sink', and that she always felt 'two steps behind the children because my background knowledge is so poor', said it wasn't a matter of having enough knowledge to answer every single question, but of having a sufficient level of understanding to feel confident in admitting to gaps in knowledge and knowing how to tackle them. In other areas of the curriculum she felt confident enough 'to first of all admit that I don't know, or try and work it out with them'. When it came to discussing her lessons in Phase 3, this teacher admitted that she tended to choose only activities which required the simplest equipment; she had tackled flight, and although she had no difficulty with the initial demonstrations of procedure, as soon as problems arose and explanations were needed she found it 'a real struggle' and was unable to either resolve the children's difficulties or probe their own resolving of problems. She would have wished for specialist help in the classroom, but more generally wanted 'idiot-proof packs' that would include all the content knowledge needed by the teacher and help in translating the 5–14 guidelines 'into what I am actually going to do with the children'.

Although there were cases where teachers came close to crying out for help because they feared losing feelings of self-esteem and effectiveness, in the majority of cases admitting to ignorance was not in itself the problem – rather it was a perceived inability to advance children's learning as productively as they would wish.

> *If I don't have that* ***real*** *understanding with a lot of background knowledge, it's more difficult to direct pupils to what they're missing .... Not that I object to saying to children 'Well, I don't really know', but that's really not much help to them ...*

Summary Points

- Teachers see themselves as needing a lot of help to teach science and technology effectively.
- Teachers request
  - inservice training
  - print materials and resources
  - more time to think and prepare
  - more/better apparatus, equipment
  - specialist help
  - school policies on timing, co-ordination, support and storage
  - suitable accommodation.
- Teachers do want help to develop their understanding, but this is far from being the only need, or even their priority.
- Better understanding of science and technology would increase teachers' confidence that they are developing pupils' ideas in the right directions.

4.6 ... about initial and inservice teacher education

The Initial Training of Primary Teachers

The courses of initial training that are described here concerned seem very different but in fact they all conform to guidelines issued by the Scottish Office Education Department. Rather than describe PGCE (Primary) courses and BEd (Primary) courses in each of the five teacher education institutions (TEI), we first spell out those parts of the guidelines that seem necessary to understand the context of our enquiry. We then go on to try to answer eight questions about initial training to teach science and technology.

Initial Training – the SOED Guidelines

The most recent version of the guidelines (SOED, 1993c) lays particular stress on the role to be played by schools in the training process and on the competences that are to be acquired during the training period. Competences are not to be seen as defining some end-point, but as laying the basis for the further development of teachers towards proficient and expert levels of professionalism. The SOED adopts a notably broad definition of competences; they are to be seen not as narrow, technical skills but as 'professional competences which refer to knowledge, understanding, critical thinking and positive attitudes, as well as practical skills'. Teachers must have a knowledge and understanding both of the content of their teaching and of the relationship between their methods and children's learning and they must be able to evaluate and justify their procedures to others.

Forty competences are prescribed and many of these are related in one way or another to our interests. One is of special relevance.

> The new teacher should be able to demonstrate a knowledge of the subject or subjects forming the content of his or her teaching which meets and goes beyond the immediate demands of the school curriculum.

The SOED guidelines give Specific Conditions to which courses of training have to conform. The Specific Conditions applying to all courses leading to a Teaching Qualification (Primary Education) are as follows.

1 Courses will be designed to train teachers to teach children of the 3 to 12 age range across the primary school curriculum.

2 Students will be given extended experience in the upper, middle and lower stages of the primary school and with children who have not entered P1 in a nursery school or class, preferably under the guidance of a nursery teacher.

3 The students' study of the primary curriculum should be closely linked to both professional studies and school experience. It is expected that the training institutions will pay attention to current national curricular developments such as, for example, the 5 to 14 Programme.

4 The students' courses should include, although not necessarily as separate studies:
   - language (English and the possibility of a foreign language)
   - mathematics
   - environmental studies (which should have a distinct science element)
   - art
   - music
   - drama
   - physical education
   - religious and moral education
   - health education
   - information technology

   Courses are also expected to deal with cross-curricular elements, for example multi-cultural education, technology and the personal and social development of children; and with the teaching of pupils with special educational needs.

The conditions applying only to BEd (Primary) and only to PGCE (Primary) are as below.

1 The BEd course leading to a TQ (Primary Education) will be a full-time course lasting for not less than four academic sessions. It may be offered at Ordinary and at Honours level.
2 School experience and related professional studies will occur in each year of the BEd course. Not less than 30 weeks will be devoted to school experience of which more than half should occur in the final 2 years of the course and include a substantial block in the final year.
3 The areas of the curriculum of the primary school will be studied (in the BEd course), although not necessarily all as separate subjects, and will form at least one third of the course. The course should also contain an optional element at a more advanced level. Students will be expected, as a minimum, to study in depth two subjects of which one, but not more than one, should be drawn from an area other than language or mathematics. A modern language should be offered as one of the options.
4 The PGCE (Primary) course will be a full-time course, lasting for 36 weeks.
5 At least 50% of the PGCE (Primary) course will be devoted to school experience which will occur in each term, with a block of four weeks occurring in the later part of the course.

There are some observations to be made about these conditions, the relevance of which should become obvious as this chapter develops.

- teachers are to be trained for all stages in the 3–12 age range and in all areas of the primary curriculum; there is no recommendation for either stage specialisation or curriculum area specialisation
- training has to pay attention to the 5–14 Programme, as the current national curriculum guidelines
- the environmental studies part of the course should have a distinct science element.

- Technology is not mentioned as a distinct aspect of environmental studies, but as a cross-curricular element.
- Curriculum studies are to form at least one-third of the BEd course; it is unclear here whether 'course' means 'course as a whole' or 'the within-institution component of the course'.
- Optional elements are to be provided within the BEd at a more advanced level; if there are two options, one of these should be drawn from an area other than language or mathematics – presumably then, one must be either language or mathematics. If three options are provided, it looks as if students are required to do both language and mathematics, ie they cannot do more than one option outwith these two.

The guidelines conclude with a checklist of questions that should be addressed in preparing course submissions. These include the following.

1 In the case of the PGCE (Primary) and the BEd (Primary) how does the course provide a sufficient level of study of the elements of the primary school curriculum to give students the ability and confidence to cope with the range of teaching required in a primary school? Does the course allow adequate time for students' learning about areas which may be new to them?

2 What arrangements are made to allow BEd students to study certain aspects in greater depth? Does the course provide a basis on which students may specialise further later in their career?

3 By what means will the weaknesses of students during the course be identified as early as possible and rectified?

A Time of Change in Training Courses

At the time of visiting TEIs, all the courses we were interested in had either undergone revision recently or were being revised for next session or even both. There were four main causes of this state of flux:

- normal requirements of institutional and course review
- a national pressure for modularisation (and in some cases 'semesterisation' as well)
- the publication of revised SOED guidelines in 1993
- the implications of progressive implementation of 5–14.

There thus seems little point in describing ten different courses in detail; the descriptions could not have any continuing validity. When trying to answer questions we shall do so in broad, general terms; where we give specific examples, we will try to indicate whether these are typical or exceptional.

How much time is given to science and technology?

This simple question is almost impossible to answer. There are two main reasons for this. First, 'time' is defined in a variety of ways – it can cover hours of lectures, student contact time, notional time (ie contact time plus an estimated figure for self-study), credited programme time (to work out the staffing earned by a course) and the length of a module (with varying or fixed amounts of contact time per module); it is often measured in hours (for within-TEI components), days (for field studies) and weeks (for school placements). Second, time is spent on science and technology which is not so labelled – it may occur within environmental

studies, within cross-curricular issues, within thematic workshops and within planned programmes of teaching; the time given to science and technology is frequently not stated, or stated to be non-determinable.

To give some indication of an answer, we will look at one example of a PGCE course and one of a BEd course – from different TEIs – and try to indicate how typical each is.

PGCE Course

In one TEI, school-based time amounts to 97 days and TEI-based programme time adds up to 380 hours. Curricular studies account for 268 hours of these 380; environmental studies gets 68 hours from the 268 hours of curricular studies time (ie 25.4%). Environmental studies is split into components (general, social subjects, healthy and safe living, science and technology). Science and technology together are given one-quarter of the environmental studies time, ie 17 hours in total.

This figure seems not atypical. Another TEI devotes 56 hours to environmental studies, of which about a quarter goes to science and technology; however, 'each aspect of curriculum studies increases its number of hours' involvement by contributions to the thematic weeks'. A third TEI gives 70 hours to environmental studies, of which 10 hours are devoted specifically to science in the upper primary and six hours to technology; this is enhanced by 10 hours for environmental studies in the lower primary and eight hours of fieldwork.

One TEI had managed to double the time for science and technology in session 1993-94 (from 20 hours to 40 hours) by using the statement in the SOED guidelines that there should be a distinct element for science to argue for a straight addition to the existing time provision within environmental studies. Only in this TEI did course tutors express any satisfaction about the time allocated to science and technology; in all other TEIs, tutors said the time allocation was grossly inadequate. Course leaders, on the other hand, pointed to the very real difficulties in satisfying competing demands for time in a course which everyone recognised as short, intensive and probably overloaded.

> *Well, possibly we should beef-up the time for science and technology, but you have to realise that the distribution of time comes about from many years of competing claims for attention. The existing course is a delicate compromise, broadly acceptable to all parties – who have to recognise the constraints of an over-burdened year and the good cases that all pressure groups and vested interests can make.*
>
> Course leader

BEd course

In one TEI, the BEd course contains 48 modules; most modules involve 40 contact hours and 60 non-contact hours (for independent study, supported independent study and preparation for assessment) but some are divided on a 50/50 basis. Curriculum studies make up half of the course (324 modules); environmental studies make up a quarter of curriculum studies (ie six modules). Science and technology account for one-third of the environmental studies time.

This is distributed as follows:

BEd Year 1	Introduction to science/technology	1/2 module	20 contact hours
BEd Year 2	Science and technology	1 module	50 contact hours
BEd Year 3 or 4	A science/technology-based study	1/2 module	20 contact hours

All BEd students thus have, over four years, 90 contact hours specifically devoted to science and technology. It can be argued that they actually have more than this because of some science and technology input to two other modules: Field-Study and Curricular Issues in Environmental Studies. This course also provides an Elective Module: Technology and Primary Practice. This occurs within a list of fourteen modules all competing for student choice.

The provision in this TEI is not very dissimilar to that in two others, or perhaps slightly more generous. For example, in another TEI two modules (each of 90 hours, with 35 hours contact) are specifically devoted to science and technology; these 70 hours science/technology contact are increased by an unknown contribution from a six-hour field day and a series of Environment Workshops.

In a fourth TEI the total time for environmental studies is similar (seven modules each involving 30 contact hours) but each module is generic in nature (eg The Local Environment and Field Studies) and the time given to science and technology cannot be calculated.

In the fifth TEI it was similarly difficult to determine what time was devoted to science and technology. In this TEI, and we stress that this was the only establishment in which a BEd course came in for criticism of this severity, tutors felt very strongly that there was a serious problem with regard to the time devoted to science and technology.

> *The standard provision is dreadful: a little in first year; a little in second and almost nothing in third and fourth. People have lobbied for years, but there are no moves afoot to improve things. The only answer is for SOED to say that there has to be a* ***separate and substantial*** *part of the course devoted to science and technology – only then will things improve.*
>
> Science tutor

> *There is a little input in science – but there is really no technology input at all. This is partly ignorance about what technology is: it is partly a foolish identification of technology with information technology. In the main, however, it is just good old-fashioned prejudice. There is a very serious bias against science and technology here.*
>
> Technology tutor

Science and Technology outwith the TEI

If we are interested in the time given to science and technology in initial training, we should have a look at what happens when students are outwith the TEI as well as when they are in it. Two types of experience are important: school placement and field trips.

School placement Students are normally expected to plan, teach, assess and write-up a teaching programme in environmental studies, associated with their school placement.

> *All students have to produce a balanced environmental studies teaching plan around an appropriate theme; they have to take responsibility for teaching and assessing it and produce a critical, evaluative account of what they have done.*
>
> Course Leader

It is interesting to note that the majority of interviewees stressed that no students could avoid the environmental studies teaching requirement, but that it might well be possible for them to avoid actually teaching any science or technology. This would usually be spotted by tutors, but not always. Students could choose themes where a science or technology opportunity was difficult to find ('The Vikings' seemed the usual example of this); they also had to take into account the plans and wishes of their host teacher. If a teacher was not accustomed to doing much science and technology, it could be difficult for students or tutors to insist that it be incorporated. Interestingly, however, there were some schools where students were used to help rectify a perceived lack of science and technology: students were assumed to be more confident and knowledgeable about science and technology than the existing staff. It was quite common for students to be asked to work up an activity in, say, design/technology and to teach it to a small group of pupils; in this way the class teacher could look after the management of the rest of the class and gain some benefit from the student's work.

Students asked by a school to work up a new lesson in science or technology commonly used the TEI as a source of materials, resources and advice.

> *They then come dashing back into college at four o'clock desperate to find out what materials we have available here and to borrow stuff from us; this is also an occasion when they feel free to ask us to increase their understanding of the necessary subject content.*
>
> Science tutor

It was rare for students, as part of their course, to have to prepare and teach a lesson on some prescribed aspect of science or technology. The position in one TEI was that students had to develop pupil materials for one science or technology target from the 5–14 guidelines, but tutors could not insist that the materials actually be used in the classroom.

Field trips Most courses of initial training included some form of field study; this could be based on one day in a local park or on a one-week residential course in the Cairngorms.

Everyone who spoke to us about fieldwork stressed its huge value; students not only gained greatly in their 'feel' for environmental science, they regularly praised the field-trip as the 'best thing in the course for personal development'; students regularly discovered a whole range of things they did not previously know they cared about, or could do.

Interviewees recognised the administrative burden in arranging fieldwork, but felt it was made worthwhile by the positive feedback from students. However, many felt the future of fieldwork was threatened by the difficulties in financing it: 'every year we have to fight the authorities to get this provision continued – they are increasingly reluctant to fund fieldwork, even when students pay part of the cost themselves'.

Fieldwork usually had a strong biological emphasis; it was infrequently related to physical science or technology.

Do course aims emphasise content or process?

From analysis of course documents and our interviews, it seems that all courses subscribe to six broad aims. These relate to the development of:

(i) student knowledge and understanding of the content and concepts of science/technology

(ii) student knowledge and understanding of the nature and processes of science/technology

(iii) skills for teaching science/technology in the primary classrooms

(iv) strategies for the management of science/technology in the classroom

(v) knowledge of the materials and resources that are available for primary science/technology

(vi) positive attitudes and confidence towards science/technology.

When we asked people to tell us what priority was attached to these aims in practice, they found it extremely difficult. One example illustrates most of the difficulties.

> *The official rhetoric would be that all of these things are very important – and there are others, for example, to show how technology is a vehicle with great cross-curricular value. We don't see content, methods and practice as separate; they are all interrelated throughout the course.*
>
> *To be honest, we keep falling between two stools – trying to educate students at their own level and telling them about activities appropriate for primary pupils. Wait a minute, can you fall between three stools? Perhaps I mean we fall off a three-legged stool: we keep trying to balance content, processes and pedagogy.*
>
> *Yes, what is the course aiming at? I don't know; and students don't know either ... .*
>
> Science/technology tutor

On a closer look at the interview data, it is clear that there is a difference in emphasis between two groups of people.

First, tutors with a background in primary schools and in the primary education departments of TEIs tended to say that the greatest importance was attached to classroom skills and then to science/technology processes.

> *We target teaching skills – because the staff in the subject departments don't see it as part of their expertise; they quite often only have experience of secondary schools.*
>
> Primary education tutor

> *The students' perception is that there is too much content in these courses; this tends to face them with their own subject deficiencies, so then they worry about their confidence. If you can help students to see that science-type processes are familiar, everyday things, this isn't nearly so threatening to them – and possibly to staff as well. I happen to have a science degree, but my colleagues don't; they are happier leaving the content of science to other people.*
>
> Primary education tutor

Second, tutors from science and technology departments, who usually – but not always – had secondary school teaching experience, said that in practice the greatest emphasis was attached to appropriate materials and resources for science/technology and that a concern for student understanding of content and concepts came second.

Students have to know some key ideas in science and technology. They have to understand what it is they are trying to help pupils to understand. We take content understanding very seriously; but we have to be careful and selective; we mustn't put people off.

Science tutor

We used to do a tremendous amount on pupil activities, pupil work cards, apparatus and equipment and commercially available text-books and materials. The emphasis has probably shifted to helping students with the background knowledge they need to deal with the bullet points (key features) in 5–14.

Science tutor

There was general agreement that aim (iv) above, the development of classroom management strategies for science and technology, was the one that courses actually did least about; such issues did, however, arise regularly when tutors' visited students on school placements.

The position with regard to aim (vi) was fascinating; half of the tutors (regardless of their department) said that this aim had the highest priority – the other half said it had the lowest.

There is no time to do anything at all in the PGCE about confidence and attitudes; we can do nothing about them in the main BEd classes either. If we focus on confidence at all, it has to be in the electives.

Head of Science Department

The whole course is about creating confidence; this has to come first – if that's there, everything else can follow; if it's not, you can pack up and go home.

Science tutor

It seems likely that staff would agree on the desirability of producing teachers with positive attitudes to science and technology and with the confidence to teach them, but are unsure about how confidence and attitudes are fostered and whether they have the time to do this effectively. To say that staff are unsure about how best to develop confidence, does not mean that they fail to achieve such development in students; evidence suggests an impressive growth in confidence over the training period. (Gooday, 1993)

To return to the original question, both content and process aims are pursued (amongst others) in training courses; the priority attached to each varies from one tutor to another – and from one TEI to the next. There is also a perception amongst staff that the relative emphasis is shifting.

In all the places we visited, there was evidence of lively debate about the importance that ought to be placed on content and process aims. These quotations illustrate the range of views.

If anyone still holds the position that process is all; they will have to retreat from it; the climate is forcing a re-definition of priorities ... .

TEI I – Primary education tutor

The time has come to demolish once and for all that there are content-free processes. How can people hold untenable views?

TEI II – Inservice co-ordinator

*I **believe** in the process model; all teachers are capable of getting pupils involved in the activities of science and technology – once they are involved, they enjoy it and they want to continue. To say science is an accessible way of finding out about the world doesn't frighten teachers – you can encourage them gently along. However, I suppose process can't be enough ....*

TEI III – Science/technology tutor

Investigation, as a process of science, is a good way to organise the science activities of pupils; but it has to serve the purpose of concept development in pupils. De-contextualised processes, detached from any knowledge base, probably don't exist. I am encouraging staff to swing the pendulum back to a more balanced view of content and process.

TEI IV – Course leader

*Beginning teachers do need a real understanding of the **content** of science and technology; we have tended to dodge this in the past by focusing on process. With 5–14, we now find ourselves saying 'you need **enough** understanding of content – not everything at once, but enough to help you develop pupil understanding in the appropriate direction'. We used to insist that awareness of the processes would provide the confidence to get started; we tended to dodge student concerns about their not understanding enough. Students accept that they cannot be expected to answer every question a bright pupil asks; but they realise it won't help their confidence never to be able to respond effectively to pupils' content questions.*

TEI V – Science tutor

We want to deal effectively with the development, at their own level, of students' understanding of the important ideas and concepts in both science and technology. However, we don't know how to do this successfully in the very limited time available to us.

TEI I – Environmental Studies co-ordinator

How are science and technology courses delivered? What do they cover?

Methods of delivery in science courses

Methods varied widely from TEI to TEI and from one member of staff to another; however, there was one general model of delivery that was much more common than any other. In this, the main sessions with the students were called workshops – there was a strong practical focus. On average, about 20 students would come together with a tutor for, say, $2^1/_2$ hours. The session would begin with a teaching input from the tutor, outlining the theme or topic, putting it in context and dealing with important content and/or pedagogical ideas; students would then work, individually or in pairs, around a circuit of practical stations, at each of which the student would carry out some activity suggested as appropriate for pupils; students would normally have some kind of workshop manual or booklet in which they had to record results and answer questions about the way they might use such an activity in the classroom; the session would then conclude with a summing-up by the tutor, usually with more guidance on the implementation of the work in classrooms. A common variant of this approach was for any one student only to do a selection of the tasks/stations; students then gave a 'presentation' on one of their tasks to their fellow students.

Most of our interviewees told us that their workshops always involved a balance between activities suitable for pupils in classrooms and for students 'learning at their own level', and that they usually felt a tension between breadth and depth – either they attempted a lot and it felt superficial, or they went for

depth of treatment and felt they had been too selective in the topics and issues they covered. Unsurprisingly, tutors stressed that it was one of their major aims to encourage students to learn for themselves; there certainly wasn't time for them to do all the learning that was necessary during the contact-time. There was some scepticism about the use made by students of the workshop manuals; several tutors told us that students did not complete these and digest the contents during or soon after the workshop; they tended to return to them only if they found themselves required to teach something from them while on placement, or if some course assessment required it.

There was considerable doubt expressed as to whether tutors got the balance between content and pedagogy right; science tutors kept trying to modify and improve their methods and distribution of time within the workshops. Some people were severely critical of the results.

> *Tutors from subject departments like science and technology spend too much time on some diluted version of pedagogical theory, rather than devoting their time and attention to the deep structure and conceptual basis of their own subjects.*
>
> Course director

> *Science tutors don't model primary classrooms nearly enough; everything they do ought to be clearly classroom-focused. But they don't necessarily have the background or credibility to do this. Most of them have a secondary subject background; they feel confident about the content of science – so that is what they emphasise, or over-emphasise.*
>
> Primary education tutor

It was recognised that students were being asked to engage in activities as pupils, but that they should not feel that they were being treated as children. Tutors wished their students to enter imaginatively into the world of young learners, but to reflect on the activities as mature professionals. This is not easy; no doubt some tutors are more successful than others; they certainly claimed different levels of success – for themselves, and for others.

> *No student has ever complained to me about being treated as a child. I am certain that if I ever patronised my students they would tell me about it ...*
>
> Science tutor

> *Let's face it some students quite like being asked to do childish things; it actually helps their confidence, they see science isn't too hard. However, there are complaints; usually about tutors from primary education. They know they are good as teachers of young people; they are less confident when dealing with adult learners – they do tend to infantilise their students.*
>
> Science tutor

In each of two TEIs we encountered one tutor who had a strong enthusiasm for a teaching method not generally embedded in the course documentation. These two people had a passionate commitment to a constructivist approach to young people learning science; they wished their students to adopt that approach when they became teachers and believed it ought to direct both the development of student understanding of science ideas and student understanding of pedagogical ideas.

> *When I realised just how exciting it was to look at pupils' learning in science, I knew that we had to try and dovetail it with teachers' understanding and their pedagogy. If students can see the excitement of pupils' developing their science ideas, then they can catch some of that excitement in developing their own ideas. This should apply both to initial training and inservice training.*
>
> Course co-ordinator

> *It is interesting that constructivism is beginning to penetrate both initial and inservice training. If it's important to look at the understanding pupils already have, it's just as important to get teachers to look at their own understanding – both of science and of pedagogy. Have you read that recent article by Stofflett? (1994)*
>
> Science tutor

It is perhaps worth noting that only in these two cases did we have evidence of decisions on methods being strongly influenced by theory-based argument.

Methods of delivery in technology courses

There was greater variety in delivery of technology courses. Workshops as we have described for science were common, particularly when they were concerned with technology seen as 'the application of science'. However, when technology was viewed as a creative design process methods changed. We became familiar with two approaches, each of which would be extended over several meetings of a group. In one of these, student work was all organised round the understanding, indeed re-creation, of some large design/technology project that the tutor had been involved with; in the other, students had to go through the stages of the design process themselves and end up with some completed product or artefact and a written report of the decision-making, construction and evaluation processes gone through. We were impressed, for example, by the design and construction of a collector for an infant playground which encouraged a sorting of rubbish for re-cycling and by the plastic tabard for teachers which seemed the ideal form of protective clothing for the teacher in an activity-based classroom.

Content coverage in science

The content coverage was organised in as many different ways as there were TEIs. Or perhaps more, because it was usual for the coverage in different years of the BEd to be organised in distinctly different ways. We could detect four distinct approaches.

(i) Broad environmental studies topics, in which science (and technology) were given timetabled 'slots' where science/technology tutors covered content they saw as important to implementing that topic in schools. Examples of such broad topics included: Europe; The Victorians; The World of Work.

(ii) Medium-sized environmental studies topics, usually planned and taught by a team of staff with different subject interests; science and technology 'opportunities' were identified, then developed by the member of staff most interested. Examples of such topics included; harbours and airports; the fairground; healthy bodies; the school playground.

(iii) Science topics, limited in scope and usually covered in one workshop session. Examples of these were: Air; Water; Electricity; Flowering Plants; Mammals.

(iv) Content organisers derived from 5–14 reports. These might be: Science in the Environment; Place, Time and Society; Living with Technology (from the draft Guidelines: SOED, 1992) or Living things and the processes of life; Energy and Forces; Earth and Space (from the 1993 Guidelines).

We could provide a detailed description of content coverage in all TEIs, courses and years of BEd courses; this would be somewhat unhelpful because much of the coverage is opportunistic and, as we have said before, courses are changing rapidly from year to year.

To get a different perspective on content coverage, we asked one or two people in each TEI whether their science courses would produce understanding of the science ideas underpinning the six topics we used in our research (Chapter 2.2). Their answers were remarkably consistent.

Arm Students would come to understand all three ideas because of content covered in their course.

Carbon Dioxide Student understanding of these ideas would be limited. They would have a general 'awareness' or 'superficial understanding' of pollution by the products of burning of fossil fuels. Unless they had the appropriate background in chemistry, they would probably not have a 'real understanding' of the composition of fossil fuels or of the concept of burning. They would know what the greenhouse effect was, but they would be unable to explain it in terms of our third idea; this required an understanding of physics which few students would have before they came – and people would *not* develop during the college course. The ideas were covered in the course materials (workshop manuals or supplementary materials), but students could not be guaranteed to study these – and they would not normally have their understanding formally assessed or confirmed.

Mirror Students should come to understand all three ideas. However, two tutors said that students would have difficulty in expressing their understanding of the third idea; they felt this was a good case of the difference between 'sort of understanding something' and being able to choose words that expressed the idea clearly; their courses, they said, were short of time to build in much *discussion* of scientific ideas – students did not always reach confidence that they were using the appropriate vocabulary.

Water All of these ideas would be covered; students should easily develop understanding of them.

Fish Students would, by the time they had completed the course, have a good understanding of adaptation to the environment; their understanding of the theory of evolution would be insecure. The ideas were covered in the manual or in background reading to which students were referred; only a minority of students would develop their understanding by these means. They would never be assessed on such understanding.

Circuit Students would develop understanding of all three ideas during their course; the ideas looked easy – one might almost assume that students would have such understandings inevitably, without much science in school or in the college course. The third idea (changes in form of energy) was perhaps slightly less likely to be well understood. There were always students who worried about

electricity, but this was due to a proper acknowledgement that some questions about the nature and origin of electricity were extremely difficult to answer in a satisfying way.

These predictions about the understanding likely to be possessed by teachers entering the primary schools at this time should be considered alongside what has been said about the understanding actually possessed by practising primary teachers in Chapter 4.2.

Three conclusions seem justified here.

- There is considerable agreement between what tutors say their students *will not* understand and what teachers *do not* understand.
- Tutors are somewhat optimistic in predicting what science ideas teachers will understand; perhaps they believe that students and young teachers do more supplementary reading and study than is actually the case.
- Tutors know very well that they have to be highly selective in deciding which ideas they have time profitably to develop within their courses.

Content coverage in technology

We cannot summarise this in a helpful way for several reasons. The courses as described in official documents are very different and, in addition, individual tutors tend to be enthusiasts with very personal approaches. Further, some approaches tend to lead to negotiation with students of content covered. Finally, things are changing very rapidly.

There is a clearly perceptible trend for teacher educators to bring their courses into a clearer relationship with the 5–14 Guidelines; for example, in two TEIs the main sections of the course are labelled Understanding and Using Technology in Society and Understanding and Using the Design Process. We note in passing that if the Framework for Technology Education (SCCC, 1994) proves to have value as a tool for assisting curriculum audit in our schools, it ought to be useful in reviewing and evaluating what is being provided in Technology Education courses within TEIs.

Are integrated Environmental Studies an effective way of developing scientific and technological understanding?

This issue is clearly one which arouses lively, sometimes passionate, debate within TEIs; all of our interviewees spoke at length on this. It was noticeable how often discussion tended to use the words of Michael Forsyth in the foreword to the draft Guidelines (SOED, 1991); they did not, of course, all agree that

> ... a subject-based curriculum provides a robust, yet flexible, curriculum which assists continuity between the later primary and early secondary school stages ...

The majority were quite clear that environmental studies embodied principles which were appropriate for the learning of young children; there were differing views about the effects of integrated study at the upper end of the primary school; views differed sharply about the desirability of *students* learning about science and technology within environmental studies. Broadly speaking science and

technology tutors favoured some distinct provision for science and technology; tutors with a primary education background were fairly confident that science and technology could be satisfactorily treated under 'an integrative umbrella'. The variety of views can be seen in the following quotations.

> *Environmental studies, in conceptualisation and manifestation, is seriously weaker than worthwhile study within the separate domains of science. Indeed, environmental studies are positively damaging to scientific conceptual development and lead students and pupils away from science.*
>
> Course leader

> *Environmental studies stresses the way that individuals learn; it is focused on a real aspect of the world and cannot be chopped into artificial, compartmentalised subjects. Environmental studies can and does work – and when it works well, it really generates interest, curiosity and productive learning.*
>
> Primary Education tutor

> *If we have to fight for a place for science /technology within a great big module called 'Europe', then we really risk losing the opportunity to develop sound understanding of the key ideas of science and technology.*
>
> Science tutor

> *Although I am still hopeful that the E-S guidelines will give sufficient emphasis and input to science and technology, I do have considerable sympathy for those who argue that science and technology must have a distinct place. It is just too easy for students to say 'I have done Environmental Studies, therefore I must have done some science and technology'. All they have probably done is a bit of library-based study and a wee bit of nature study ... .*
>
> Science tutor

> *I really welcome that bit in the guidelines about a* ***distinctive*** *element about science. This should apply to all PGCE and BEd courses. I will use this to keep pushing ...*
>
> Course leader

That final quotation catches the note of determination expressed by most science / technology tutors. They felt that the 5–14 Environmental Studies document and the SOED Guidelines on Training had 'strengthened their arm to fight for a clearer place in the sun' for their subjects.

How do courses cater for differences in scientific background and understanding?

We asked people about the amount and nature of the differentiation they introduced into both BEd and PGCE courses and how they were able to respond when students revealed some lack of understanding. Before we look at what tutors actually did, there are three points to deal with in preamble.

First, differences in subject background in the sciences are not the same as differences in understanding the important concepts of science. Our interviewees told us, for example, that it was possible to complete Standard and even Higher Grade courses in science subjects and still not have attained understanding of some important concepts in that subject; it was possible for some students to have a good understanding of science ideas without examination passes – through a general experience of living, the media and their personal reading. Students

could have a Higher in one science (or, in the case of PGCE students, a degree pass in a science subject) and have little or no understanding of the crucial ideas of other sciences.

It was also desirable to distinguish between understanding a science concept (content knowledge) and understanding how to represent that understanding in ways which made it accessible to a variety of learners (pedagogical content knowledge).

The second point is that several interviewees reacted against any form of words which might be thought to imply that students were in any way deficient: 'I cannot operate on any kind of deficit model'. If students did in fact possess development needs, this simply put them in the same category as all other human beings; there was no way that students were to be blamed for not possessing some understandings that some authority (policy document or college tutor) was now saying they *ought* to possess.

Tutors felt they could legitimately criticise students for not making the effort to understand things they newly recognised it would be helpful for them to understand as teachers; they would not criticise students for any other 'deficiencies' in scientific understanding.

The final point concerns different levels of understanding. Interviewees pointed out to us that understanding was something that people possess to widely varying degrees and that there is no final, definitive, correct understanding of a scientific concept. Therefore we were not talking about 'no understanding' on the one hand and 'complete understanding' on the other. We had to face very difficult decisions about the level of understanding that was desirable for whatever purpose we were trying to fulfil; primary teachers needed 'some understanding' of scientific concepts in order to develop these concepts in their pupils. There was no easy answer to the question 'How much is some ... ?'

Tutors recognised that if this was true of students it was also true of themselves.

> *Colleagues in the science departments think that we in primary education don't know enough science ourselves – and in some cases that is probably true. But, I am pretty sure that there are biology tutors who wouldn't claim to be very good at physics. How much science have you got to understand to be an effective primary teacher?*
>
> Primary education tutor

People in all five TEIs were agreed on the need for some differentiation in their courses; similarly they stressed the difficulties in achieving effective differentiation. In one TEI the difficulties seemed to have overwhelmed any impulse to action; in the other four a variety of actions were being promoted with considerable vigour.

The need for differentiation stemmed from one single long-standing cause. There was an extremely wide range of previous science experience and qualifications in the students: there could be BEd mature students with no school science beyond S2; most young students had some science to Standard Grade – but more commonly in biology alone; it was rare for BEd students to have a Higher pass in a physical science, physics or chemistry. Occasionally a PGCE student would have a science degree; more often they had degree passes in biological, social or psychological science subjects; the large majority were

perceived by their science/technology tutors as being 'arts-biased'. (We do not have hard figures on this last point; there is scope for further research here. We were struck by the frequency with which interviewees claimed art-bias in students, in primary schools, in their TEI, in our whole culture and that all these biases interact and serve to perpetuate each other.) The pressure to move towards more effective differentiation (in four TEIs at least) was said to have increased significantly because of 'the expectations of the present'; these were seen as an increased emphasis in 5–14 Guidelines on pupil understanding of science concepts and the explicit mention in the SOED Guidelines on Initial Training of teachers' knowledge of their subjects being required to meet and go beyond the immediate demands of the curriculum.

The difficulties of instituting effective differentiation seemed to be of four types; they related to student attitudes, activity management, staff/student ratios and the availability of time.

Student attitudes

Some of our tutors told us there was student resistance to any increased emphasis on scientific understanding and student reluctance to reveal any lack of understanding.

> *Students – particularly the less mature BEd students – are very reticent about revealing any lack of understanding. Partly it's the difficulty of knowing what it is that you don't know; but partly they are very conscious of their lack of knowledge, most especially in technology and physical science. If you give them more science content, without really convincing them that they need it, then you are in trouble. When it comes to course evaluations, the demanding courses are downgraded ... .*
>
> Head of science department

Activity Management

Some tutors drew our attention to the fact that the management of differentiated activities within any learning situation is always difficult, but it is particularly challenging with adult learners who can be sensitive about their perceived shortcomings. Graduate students come in groups of, say, 20 – and sometimes more; it was important that they covered a lot of ground, shared experiences with each other and learned from each other. Given a time allocation for student contact in science and technology that almost everyone thought too little, the opportunity for effective differentiation was limited.

The difficulty was stressed most by those who had one particular view on how lack of understanding had to be addressed.

> *If you want to develop genuine understanding of big science ideas then you have to do it in small groups with a trusting, non-threatening atmosphere. You have to start from where the students are – and that's often a long way back; you have to listen very carefully; they have to be able to check out their developing ideas against others ... . Such group work with a small number is very difficult to manage in the middle of a busy workshop.*
>
> Science tutor

We hardly need comment that these words could have been spoken by a teacher about teaching science in a primary classroom!

Staff/student ratios

It was frequently pointed out that current methods of calculating the money available for teacher education courses and their components meant a significant pressure to increase class sizes. Course leaders found it difficult to justify having smaller groups in certain subjects and not others. So-called 'efficiency savings' made members of staff feel they were being inefficient if they argued for smaller groups; they sometimes could only have smaller groups by agreeing to teach more hours than they would actually be credited with.

The availability of time

All members of staff pointed to their own increased workload; this made it difficult to find the time to re-design courses and workshops and to produce learning materials differentiated in relation to student needs.

There was, however, a difference of opinion about how much time students had and how hard they worked. The number of contact hours was generally thought to be much too low, particularly for those students who had little or no science background. Some staff thought BEd students had too much non-contact time for self-study; others thought they had too little time outwith classes as it was – and to attempt to use some of that time to improve their own scientific understanding would be unreasonable. The scope for differentiation within the contact hours was limited; the scope for differentiated, supported self-study was seen as problematic. As far as PGCE students were concerned, the time for effective differentiation was very seriously limited; they had very little contact time for science/technology and the course as a whole was thought to be both over-taught and over-loaded.

Given the need for differentiation, and the difficulties, what is actually done? This can be considered under four headings:: early diagnosis of differences, small group tutorials, provision of support materials and responding to individual requests.

Early diagnosis of differences

Several tutors made a point of spending time early in the course in making very clear just how different people were with respect to the amount and nature of science in their background; they did this within a climate that stressed 'we all have different strengths, we have to learn from each other'. Students were encouraged to reveal their anxieties about lack of subject understanding in science and technology; tutors outlined the ways in which they would try to help.

In one TEI early meetings dealt with content only, diagnosing the level of understanding of students of key ideas. Certain students would be advised of ways in which they should remedy their lack of understanding. One tutor said s/he expected all students to attain a minimum level of understanding, equivalent to Standard Grade, in biological and physical sciences before they could proceed to benefit from the teaching methods element of the course.

In another TEI, a head of department had argued during course revision that students should have to sit pre-tests of their understanding of science and then, if successful, be exempt from the early content sessions. This proposal had not been accepted, but s/he expected it to be repeated and received more favourably in future.

Small group tutorials

In two TEIs, staff had insisted that necessary differentiation could not be achieved through the workshops and had to be pursued through tutorials with smaller groups of students (say 10 or 12). Although institutional authorities saw this as a use of staff time that was expensive, tutors were firmly convinced of its desirability and effectiveness.

Provision of support materials

In all five TEIs efforts were made to provide students with supplementary support materials; the emphasis on this had increased considerably in the last year or so, in four of the five. There were four types of material:

- lists of references to commercially produced texts that included science background, 'teacher knowledge', materials. (English publications for Science at Key Stage 2 more favourably mentioned, eg *Primary Science: A Complete Reference Guide*, Evans, 1994)
- brief handouts provided by tutors, relating to the subject knowledge for each workshop (and usually cross-referenced to the 5–14 Guidelines)
- booklets on broader topics, provided in multiple copies for loan and consultation in the library. (One TEI had developed a series of FLOPPIES – Flexible Learning Opportunities; these were said to be welcomed by students as essential 'life-rafts for survival'.)
- substantial readers related to the main 5–14 Attainment Outcomes, each designed to cover the necessary understanding of main concepts and key ideas of science – aimed at both students and practising teachers. (See, for example, *On Planet Earth*, MacGregor, 1994.)

Responding to individual requests

All the tutors we spoke to said that their most effective work in dealing with a lack of understanding of science and technology was probably done in a responsive mode, ie reacting to requests on a 1:1 basis from students. This happened during workshops; it also happened when students came into the TEI seeking help with something they had to teach while on placement.

Some students regularly sought help; others did not. It was recognised this support was patchy and unsystematic. Probably many misunderstandings went unrevealed and unremedied. There was a degree of bitterness amongst the tutors who spoke to us, that this work of theirs went unrecognised and uncredited by those 'accountancy-minded' people now thought to dominate amongst TEI managers.

> *I have spent un-numbered hours supporting students in this way. They badger me for help with science content and with gaps in their understanding. No-one over there is interested ... it doesn't count ... .*
>
> Science tutor

Does scientific background influence the selection of students?

There are currently far more applicants for BEd and PGCE courses than there are quota places; this applied in all the TEIs; the ratio of applicants varied from 4:1 to as high as 12:1. All of the people who spoke to us stressed the very high calibre of students they now had on courses of initial training for the primary school.

Because of the high numbers of applicants, it was usual to do the selection of students in two stages. The first stage had to be on the basis of information provided on paper – initial selection criteria had to be capable of being operated in an objective way by a registry clerk with perhaps computer assistance; such a process stressed the easily quantifiable, like the number of 'points' gained in Highers. The second stage involved a face-to-face interview where the selectors were looking for commitment to teaching, some knowledge of contemporary primary schools and for a wide range of personal qualities and relevant interests.

BEd students are required to possess Higher English and either Higher or Standard Grade mathematics. Science qualifications rarely entered into consideration.

> *Of course, English and maths are essential. We never look at passes in science or technology. Would it be helpful? I doubt it. What would a pass in geology or biology tell you about their abilities in other sciences? Well I suppose, all other things being equal, we might look favourably on the possession of a science ... .*
>
> Course leader

PGCE candidates were required to have a degree and a pass in Higher English. We were told that it was unusual for applicants to have a science degree; it was estimated that perhaps 10% had a fair amount of science in their degree, but no firm figures were available.

> *And the degrees cover a weird and wonderful range of obscure subjects; they may have no relevance to the primary curriculum at all – and this may be no bad thing. We do want our PGCE students to have a good mix of backgrounds. If the degree has no relationship to the primary curriculum, we try to take into account their school passes – so that across the degree and school qualifications as a whole there is some kind of relevance and balance ... .*
>
> Course leader

Selection processes are kept under review and change from year to year. For example, in one TEI it has been decided that PGCE students *must* from now on have one Higher science pass; session 1994–95 will be the first session when all PGCE students meet this requirement.

We were rather surprised that there seemed to be little evidence about the nature of the qualifications possessed by students, or if it existed our interviewees were not familiar with it. We should also note that there was considerable uncertainty over the actual selection criteria used; in one TEI we were given quite contradictory messages about selection to one course. This may be due to the rate at which processes and criteria are currently changing. (We are aware that the SOED is reviewing the Memorandum on Entry Requirements to courses of teacher training.)

Clearly there are very difficult issues raised by any move to take science qualifications more seriously into account. We hope that in the resolution of these issues due attention will be given to a view expressed by several of our interviewees.

There is something wrong with a society in which it is still acceptable to admit scientific and technological illiteracy; that bias in society is perpetuated by our schools and colleges. What is essential is a re-definition of the necessary basics; it won't do any longer to say that English and mathematics alone are basic and essential. It has to be English, maths and science ... .

Course leader

Is scientific and technological understanding developed in options?

In earlier sections we looked at the aims, methods and coverage of those courses which all students had to take. Perhaps scientific and technological understanding are significantly developed through optional and elective courses?

There were no optional courses in science or technology within PGCE programmes. All the BEd courses had options/electives.

The options really matter. This is where you can really help with students' own development: they are the crucial setting for developing confidence.

Head of science department

However, the general picture as regards numbers of students choosing to do an option in science or technology is very gloomy. Most TEIs estimated that 10% or fewer of students now elected to follow a science or technology option. There were two reasons for this.

The first was that the SOED guideline on options [see page 145] had commonly resulted in there being two option lists, one of which contained Mathematics and Language, the second of which contained everything else. Science and technology had to compete against ten or twelve other options; added to this, there was increased official opposition to classes running with numbers less than the minimum judged to be viable. In two TEIs, technology options did not run in session 1993–94 because they failed to attract adequate numbers.

My option on Technology always used to have about eighteen students when it was competing against fewer other subjects; last year it was down to eight and this year it was cancelled. It was a good course; practical and challenging, we got excellent evaluations ... .

Science/Technology tutor

The second reason was said to be that students were feeling the pressure to succeed in the course as a whole and thus choosing options which were perceived as easier. Performance in options was taken into account in progress regulations and, in most cases, could affect the final degree result and honours classification.

There are two principles here. Students should choose an option because they recognise it will fill a need, it will help them to become better at something they are not so good at; on the other hand, perhaps if they are already good at something they should choose to enhance that further. Can we blame students in these harsh times, when they are competing for too few jobs, if they go for something where they avoid the risk of failing? Students are not good at physical science and technology – the numbers in these options are falling.

Course leader

The option picture was a dark one, from the point of view of the development of understanding of science and technology. There was one bright exception.

> *My technology option routinely attracts about 25 out of the total 100 students. The option isn't a soft one – but word has got around that it's enjoyable. Even more importantly, word has got round that schools are starting to look for beginning teachers with a proven strength in technology. I met one of last year's students in a school recently and she immediately told me that she had got the job because the school were impressed by her technology portfolio.*
>
> Technology tutor

In another TEI, a tutor was pressing for there to be introduced a system where performance in one of the options could be discounted, ie students could be positively encouraged to take an option to remedy a weakness without there being a serious risk of this jeopardising their overall success. S/he argued that as the 5–14 Environmental Studies guidelines assumed ever greater priority, schools would increasingly look to students who had developed their understanding and skills in science and technology.

How are courses currently changing?

We asked interviewees how courses were changing, in ways that related to the preparation of primary teachers to teach science and technology in schools. We summarise below the views expressed, with an indication of what was said by how many people and from which institutions.

Every curricular area is pressing for more time and a higher priority; there will be little net change in the time allocated to science/technology.	The majority of course directors/leaders.
5–14 Guidelines on Environmental Studies and the SOED Guidelines on Training will help us get more time and greater recognition.	The majority of tutors in, and heads of, science/technology departments.
The 5–14 guidelines state that 25% of the school curriculum should be devoted to Environmental Studies; college courses will shift to ensure a similar balance.	Three course leaders.
Current revision of the BEd will lead to a more subject-based, content approach; we are choosing external examiners who will encourage this change.	Two course leaders.
Science will be putting more emphasis on physical science; this reflects the balance of attainment outcomes in 5–14 ES.	The majority of science tutors and heads of department.
The 5–14 ES guidelines put greater emphasis on content coverage and conceptual development in pupils; our courses will increasingly try to deal with student *understanding* of key ideas in science/technology.	Majority of science/technology tutors.

All our courses will have to tackle more coherently and systematically the implementation of 5–14 Guidelines in schools.	All interviewees.
The general educational climate emphasises more and more the understandings that pupils and students bring to their learning; we will adopt a more constructivist approach.	Tutors in two TEIs.
There is so much pressure on initial training that we will have to stress that much of the development of teacher confidence and understanding will depend on later professional development; we will encourage the development of post-initial award-bearing courses.	The majority of all interviewees.
The publication of a Framework for Technology Education (SCCC 1994) will help us to press our case for more time and resources.	All technology tutors and heads of departments.
Overall college policy stresses modularisation; we will have to fight even harder to give science and technology their place within that structure.	Tutors in two TEIs.

Inservice Teacher Education

Short courses and school-based inservice

In three of the five TEIs, their involvement in inservice courses and school-based activities in science and technology was said to have declined to virtually nothing. The reasons given for this were:

- devolution of financial decision-making to school level meant that individual schools were unlikely to be able to afford to seek inservice provision from TEIs
- education authority advisers were increasingly keen to provide inservice support themselves, rather than seeking it from TEIs; they were thought now to be 'buying-in' only what they were unable to provide themselves
- the phasing-in of 5–14 meant that most provision had been in maths and language; the demand for science and technology would come later
- the number of staff in TEIs had decreased; the small number now remaining were fully occupied, with little time to stimulate and provide inservice training.

In the other two TEIs the picture was different. One had a long-standing record of provision to small, remote and rural schools and this had held up well, perhaps particularly in technology. Another had one member of staff who was much sought after by the education authority to provide short courses; s/he attributed this to the fact that s/he was a former primary headteacher and was perceived by schools as a high credibility training supplier.

It was notable that in both the above cases the tutors had operated, not through one-off attendance at a course in TEI or teacher centre, but through a programme requiring first attendance at a course, then the trying out of activities and materials in schools, then return together on a follow-up day for reflection on successes and problems. Teachers had been encouraged to set up a 'support network' and to telephone each other and the tutor for help and encouragement. The major purpose of the inservice technology courses had been familiarisation of teachers with the nature and purposes of modern approaches to Design/Technology in the primary school; the main areas of need in science had been identified as Forces/Energy and Earth/Space (from the 5–14 Guidelines). Although the overt purpose was to provide suggestions for appropriate classroom activities, teachers were said to have revealed a lack of confidence in their own knowledge and understanding of the key ideas in these topics.

The extent of provision of this kind of inservice support throughout Scotland would obviously be seriously underestimated if provision through TEIs alone was considered. We thus sought information from the Chief Adviser (Primary) of one very large education authority. He made four preliminary points:

- the major thrust in inservice training in science and technology would not come for two or three years due to regional policy for the phasing-in of different aspects of 5–14
- the inservice support supplied by the region would attempt to meet the professional development needs of staff as highlighted by School Development Planning
- most primary teachers have an interest in and enthusiasm for teaching science and technology; their problems stem not from a lack of understanding of these curricular aspects but from extension of their role, the pace of change and generally increased workload. All of these had reduced the availability of *time* for 'quality thought'
- the region's courses would probably continue to have a practical focus. One could expect issues of equipment and resources, the safe management of science/technology activities and the implications of classroom design and facilities to continue to dominate.

This region would provide at least 37 courses in Environmental Studies between September 1994 and March 1995; these would normally be one-day courses, with the possibility of some follow-up. (This number of courses compared favourably with the 25 on offer in Expressive Arts in the same period.) It was hoped each course would attract between 16 and 20 teachers, ie perhaps 700 teachers in total.

These 37 courses fall into five categories

1 *Environmental Studies:* 14 courses
General and non-science/technological

2 *Introducing Technology* 13 courses
These aimed either to review technological activities appropriate to P1–P3 *or* to explore the integrative role of technology within a topic-based curriculum *or* to introduce teachers to control materials using LEGO.

3 *Science – An Investigative Approach* — 5 courses
These aimed to develop science investigative skills within the context of 5–14 Environmental Studies.

4 *The BP Contexts Box* — 3 courses
These courses would demonstrate the use of the BP resource to cover a variety of science and technology topics.

5 *Science – Background Information* — 2 courses
These courses would aim to provide 'background information to provide confidence in developing the key features of science'.

It is interesting that the last category contains the only courses (ie 2 out of 37) that explicitly recognise there *could* be a lack of confidence or a need for *background* information amongst teachers. It is clear from the discussions in TEIs that 'background information' is now the accepted code-word for 'materials to develop teachers' understanding of science and technology'.

In another region, although the science adviser had a secondary science background he had developed a keen interest in science and technology in the primary school and had worked up a series of meetings for primary teachers on a sequence of four Wednesday evenings. This was in response to identified needs and was in advance of the phased regional programme for environmental studies. These meetings had been hugely over-subscribed – he would be repeating the provision several times throughout 1995. Three points about this particularly interested us. Firstly, this adviser believed there was no gain involved in distinguishing science and technology at this stage: 'we are teaching teachers science, but they get it put into action as technology'. For example, one of his evenings started with the construction of a simple chassis with wheels and then a motor was added; the 'homework' for the next evening was thinking about how to design 'headlights' which could be switched on and off – so time at the second meeting was devoted to learning the science of simple electrical circuits. Secondly, the adviser stressed that there would never be time to do everything with teachers; thus you had to create confidence in teachers through practical involvement in limited activities and point out to them that they were well able to identify other opportunities themselves. The purpose of the evenings was centrally about confidence-building. When he was asked how he could tell if confidence was increased, his answer was as follows.

> *You can easily tell from their faces: they look happier– they smile – a furrowed brow clears. This seem to happen for three reasons: they* ***understand*** *something they didn't understand before; they build something and it works; they suddenly see how a suggested activity can be built into what they plan to do – they see the relevance.*

Thirdly, the adviser realised that the size of the demand for science/technology inservice could not be met by him alone; he had thus set up a pilot scheme for neighbourhood tutors based on cluster groups of a secondary school and associated primaries. In this, a secondary teacher acted as link person. The success of this was 'varying'. In one case a very enthusiastic young chemistry teacher had established very valuable links; in another a headteacher had condemned the exercise as 'inservice on the cheap' and all interaction had rapidly foundered.

This adviser had also developed a staff development package, in conjunction with Scottish Power, on Basic Electricity. The package was distributed to other authorities via the Scottish Science Advisers' Group. Staff development materials on other topics, for example Energy and Forces, are now being produced with such support from business/industry and distributed in similar ways.

In the third region, a very ambitious and comprehensive programme of short courses had been devised. This again used cluster or area-groups of schools; from these one person (from a primary school) was identified as the lead or reference person for the group for each aspect of environmental studies. This person would attend inservice courses at the teachers' centre and then become the 'tutor' for future inservice based on the area-group. Each course involved attendance at the regional centre and involved the development of a term's work on a project of the teacher's choosing. Advisers in this region made several points about their inservice plans.

- They did not overtly claim that their programme had anything to do with increasing teachers' understanding: the admitted purposes were concerned with confidence-building and the skills involved in planning and implementing environmental studies programmes. The advisers held that what was necessary was to get teachers to think 'in a scientific/technological/problem-solving sort of way'; they placed emphasis on the nature and processes of science.

However, they conceded that when the issue of *progression* in primary school science is taken seriously, then more direct work on conceptual understanding in both pupils and teachers would be necessary.

- The approach in technology and in science courses should be rather different. In technology (with the exception of aspects of control technology) all that teachers had to do was to recognise that much of what they already did was technology, but described in a different language; if teachers were 'thrown in at the deep end' they would quickly discover their ability to swim.

In science, however, knowledge and understanding of some 'hard' science was becoming necessary in a way it had not been before. Background knowledge would have to be fed in, in future, in manageable, easily-digested chunks; if teachers were thrown in at the deep end they might well drown.

- From 1995 onwards schools would be able to choose whether their main inservice priority was Environmental Studies, Expressive Arts, or Religious and Moral Education. This meant that the delivery of courses in these areas would have to be carefully planned to cover an extensive period; it was going to be exceedingly difficult to provide coherence and continuity over this period. It needed budgetary provision guaranteed over at least a five-year period; in the current financial situation in local authorities, they were forced to plan from one year to the next.

- Difficult decisions had to be taken about the relative value for money of a planned programme of courses (which might involve paying cover costs to release teachers from schools) as against employing development officers/advisory teachers to support teachers within their schools without daytime release. Advisers would like to do both, but felt it unrealistic to expect the necessary funds to be available.

If the picture in other regions is similar it is difficult to know what concluding comment to make. One could say that it is encouraging and impressive that so much is happening when science / technology inservice is not a priority; one could say that this is an extraordinarily small base from which to grow the massive provision that will be necessary to supply needs from two years hence.

What award-bearing courses are there?

Postgraduate Certificate in Environmental Studies

This award-bearing course was initially validated in 1989, then revised and re-validated in 1994. The course is delivered through distance learning and administered by the five TEIs with *University of Strathclyde (Jordanhill) being the host institution.

The course now has one compulsory module (Programme Planning: The School Context); three other modules are selected from a list of options which include Assessment, Resources, Research and Issues in Environmental Education. From 1994 one relevant module from a validated certificate course in Science or Technology or Health Studies can be included, ie can count as one of the optional modules.

The course concentrates on the planning, implementation and evaluation of whole-school provision of Environmental Studies programmes, focusing now on the 5–14 Guidelines. It adopts an integrated approval to environmental studies, the contributing subject elements not being emphasised or made distinct. The course overall is not designed to develop students' own understanding of the *content* of environmental studies. It may or may not be significant that the members of the planning group for the course all have a background in the social subjects, geography and / or history.

Significant numbers of teachers have enrolled on the course; for example in the University of Strathclyde (Jordanhill) there have been 200 enrolments since January 1990. Due to the focus of 5–14 implementation so far being on curriculum aspects other than environmental studies, the numbers of teachers completing the courses has declined in recent years. The organisers hope for sustained enrolment and higher completion rates when environmental studies comes centre-stage in development priority.

The general reaction of our interviews is indicated by these two quotations.

> *I think because of the SOED/SHEFC subsidy of this course, it should be seen as a bargain. Will local education authorities continue to fund some teachers to do it? Only large schools, with environmental studies top of their development priorities, will be able to give teachers financial support for this. Will individual teachers pay for themselves – to do modules which have to be taken end-on to a busy day or a busy year?*
>
> Inservice Co-ordinator

> *This is a good course for those with a curriculum leadership role; it doesn't pretend to have much to do with enhancing an individual's teaching effectiveness in the classroom. No doubt there is some spin-off of this kind .... It's got little to do with science or technology at present; this could change.*
>
> Head of Science / Technology

* In this part of our report, TEIs are sometimes named; when this happens it is with the approval of the representatives concerned.

Postgraduate Certificates in Primary Science Teaching

Only one TEI has a long-established course of this type: Northern College. For a time the course was also offered by Moray House by agreement with Northern College. The course is now in its tenth year; it has been consistently highly regarded by course members, school managers and education authorities.

There are four modules: Perspectives on the Curriculum; Evolving an Effective Science Curriculum; Issues of Practical Science and The Project: Theory into Practice. The third of these is an in-college module concerned with practical activities and teachers' own needs in knowledge and understanding of science. It is regarded as essential for teachers to get practically involved and to interact with other teachers; the timing of the week is difficult and there are significant financial implications.

The course is essentially about the management of science provision in schools and in classrooms; it aims to meet the professional development needs of individual teachers, either as identified personally or as stemming from the development needs of the school. It is not at present tied tightly to the 5–14 Guidelines, but increased congruence with them is planned. The course has been *science*-focused, but a technology module is about to be provided.

The character of the course is indicated by these quotations from people directly concerned with its provision.

> *They come on this either because they see science as an area where they are weak or as an area of strength they can develop to benefit the school. They tend to see themselves as classroom teachers, science planners and consultants to their colleagues rather than school managers. Having said that, they do tend to get promoted soon after ....*
>
> *They come on by leaps and bounds in things like assessment and record-keeping; they also get better at managing their own and children's learning.*
>
> *They crawl through the door at the beginning of the Module 3 and say 'I'm really sorry – I'm so ignorant'. At the end of the week they go away smiling: 'Perhaps we don't understand any more science – but we don't worry about it any more'.*

The University of Strathclyde (Jordanhill) has started a somewhat similar certificate course just this session. The Postgraduate Certificate in Science 5–14. This course is an approved specialist pathway to a Certificate in Advanced Professional Studies, ie it is fully integrated within the University of Strathclyde (Jordanhill) Inservice Awards Scheme.

There are four modules and students take all of these: Planning for Science; Delivering the Content; Technology; Issues of Our Environment. (It is hoped that a similar specialist pathway leading to a Post Graduate Certificate in Technology 5–14 will be developed.)

The course director described the course as being for 5–14 implementers, 'to help them with their own teaching, to help others to teach science and to co-ordinate science/technology teaching in their schools'. The first module, being taken now by the first cohort of 17 students, is concerned with the nature, aims, methods and assessment of science in the primary schools. Module 2 has as one of its aims 'participants will be able to be creative and innovative in designing activities for children, on the basis of increased understanding and application of

scientific concepts and processes'; the scientific content of the course is clearly defined (under the general headings Energy, Forces, Earth and Space and Living Things). Module 3 has a similar aim concerned this time with understanding and applying the concepts and processes of Technology.

How these modules will be taught, the extent of differentiation in response to different science backgrounds and the reaction of the teacher course members is as yet unknown; this is an important development which deserves careful monitoring.

Other award-bearing courses at the planning stage

Staff at Moray House Institute are actively planning to mount a course based on one developed at Christchurch College and validated by the Association for Science Education entitled Success with Primary Science. The course originally related to the National Curriculum for England and Wales, but it has already been 'tartanised' to meet the requirements of science and technology within the 5–14 Environmental Studies Guidelines.

Although concerned with processes and investigations as well, this course is said to be much more explicitly concerned with the knowledge base that teachers require in order to foster conceptual development in their pupils. It starts from the premise that the science understanding teachers should have should be 'somewhat beyond' that to be developed in pupils because 'pupils' questions may go well beyond the minimum'.

> *We perceive the Northern College Certificate as being very much process-based. The Christchurch course is much more keen on the content of science ...*
>
> Science tutor

The intention is to work at the beginning with ASE then, when assured that standards can be met, validation will be sought within the Moray House awards framework. It is hoped that some of the first teacher-students will take appropriate additional modules in the award scheme and thus be well-qualified tutors for a major expansion in numbers expected when 5–14 Science and Technology comes fully on-line.

The industrially-sponsored package The Bicycle Pack (CIBA) will be the central resource for a Moray House course which will focus on science and technology *within* a unifying Environmental Studies context. It is hoped to develop the initial, reflective aspect and thus develop another module or course within this TEI's Award Scheme.

This approach is centred rather less around the development of the teacher's knowledge base and rather more on the enjoyment and confidence-building aspects of involvement in science and technology (as broadly conceived).

How should teachers' needs be met?

All of our interviewees had clear views, sometimes developed at length and with vigour, about how primary teachers should be supported in the teaching of science and technology. These can be grouped under five headings:

- helpful printed materials
- short inservice courses
- longer award-bearing courses
- extra people into primary schools
- networking within and amongst schools.

Helpful printed materials

Teachers need written materials, we were told, which do a variety of things: interpret the Guidelines, expand the Guidelines to indicate content coverage and pupil activities, give examples of teaching programmes showing progression over the primary years, help teachers with the necessary background knowledge.

We are aware of the work being done in Content Exemplification, the case study in primary/secondary liaison, and the assessment guidance currently being prepared under the guidance of a National Advisory Group. Our evidence suggests that all these are needed – and will be welcomed.

The 5–14 Guidelines, particularly with respect to technology, came in for some fierce criticism. Either they should be re-written, or there should be a simple interpretation of them published.

> *The Guidelines need guidelines to make them comprehensible. I found them really hard, till I decided that some of the italicised examples given on the 'battery' pages were just nonsense. I'm pulling my hair out over the* ***control*** *technology features – extremely difficult to see what is meant by them … . I don't want them radically changed, well not too soon or too often – that's irritating. Perhaps the SCC (1994) report on Technology Education will provide a good reason for revising the guidelines – or at least making them clear.*
>
> Technology tutor

The key features, foci for study, could usefully be spelled out; teachers need help to see what science content is implied by each of the 'bullet points' in the Guidelines: 'What are the *ideas* that are to be developed in these?' Appropriate pupil activities, and how to ensure they are productive, should be written up. We spoke to the authors in the SCCC content exemplification exercise and their work should go a long way to meeting this need. However, we note the view of one author.

> *I hope the stuff I'm writing is helpful. When I read it myself I see all the usual, conventional words about science education and I wonder if primary teachers will get the feel and the spirit of the whole thing? Will they get the fun and the excitement? Will they see what it's all about? Play, curiosity, excitement, discussion …*
>
> Science tutor/SCCC author

Some of those who talked to us said only one thing was necessary: a printed programme which said what topics and themes should be studied in which school year, at what time of year and for how long. The whole enterprise would become manageable when teachers could see the 5–14 Programme in small

chunks. Others of course disagreed violently; such a prescriptive, directive approach from any central source would be entirely inappropriate; if such a programme were desirable, teachers could perfectly well devise it within a school by adapting their existing programmes and practices and allocating them clearly to each stage.

This is an area where the involvement of business/industry has become much more significant. The sponsorship by BP of the Environmental Studies Contexts Box may be the best known example, but there have been valuable contributions also from Scottish Power, CIBA and Philip Harris. It should be noted that, although our interviewees praised these resources, they also had misgivings.

> *I do not think the provision of such packs is anything like an answer on its own; there really is no shortage of pupil materials and teacher materials. There is a lot of stuff on school shelves which just isn't used. Teachers don't take them off the shelves unless they clearly fit into their school-devised programmes and teachers see exactly what to do with them, when ...*
>
> Science adviser

The majority of science/technology tutors (but not tutors in primary education departments) said there was now a very real need for short, focused, accessible texts to help teachers develop the necessary understanding of the ideas/concepts within science and technology. People pointed, as we said before, to commercially available materials and the handouts and booklets they were themselves producing.

> *The big need now is for proper background materials in science and technology for primary teachers. They should be targeted at teachers as intelligent lay persons and explain the science properly and non-patronisingly. The breadth of coverage can be deduced from the Guidelines; the depth is rather more tricky – it's the depth appropriate to be able to explain what pupils have to understand, to answer their likely questions, if not their most bizarre ones.*
>
> Head of science/technology

We headed this section 'printed materials'. That's a bit misleading. Several people pointed out that sophisticated staff development materials of the kind they wanted to see should make use of educational technology, multi-media approaches including Compact Disc Interactive.

> *This would help you access all the words that seem to be necessary; you could also get pictures, for example, of pupils at work doing the suggested activities and of classroom management strategies. Staff development on the huge scale necessary needs maximum use of information technology ...*
>
> Head of science/technology

But ...

> *However good the publications and packages are, they won't work on their own. Especially if we are concerned with areas where confidence and understanding can be low ... teachers have got to interact with others in a* ***comfortable*** *sort of way.*
>
> Science tutor

Short inservice courses

Our interviewees were unanimous that printed materials were necessary, but not sufficient; there would be an increasing need for short, focused inservice courses. The staff in TEIs did not see themselves as the only suppliers of these; they praised the work being done by education authority advisers and others and looked forward to a productive partnership. TEI staff pointed to the small number of tutors they could supply and to the other demands made on their time. As a result, there was no way they could meet the large demand that was anticipated. Nor did TEI staff believe that their institutions were necessarily the best places for teachers to come together, for one thing in some TEIs the accommodation available tended to have a 'secondary-school-laboratory feeling'. Such short courses were often best located in a teachers' centre or in one school serving a cluster of schools nearby.

There was no one view of the purposes and nature of such courses. However, the points regularly stressed by a majority of people were:

- short courses should meet the needs and priorities of teachers as identified in school development plans
- there is benefit in implementation, reflection and follow-up, ('drip-feeding') rather than in attendance disconnected from practice
- where there is an emphasis on teacher understanding of science and technology, methods have to be imaginative if an increase in anxiety is to be avoided
- courses would be required for headteachers and assistant heads as well as classroom teachers
- meeting the needs of individual schools is difficult and expensive – the co-ordinating role of local authorities is vital and ought not to be allowed to disappear following local government reorganisation.

The majority also stressed that courses should have a strong practical emphasis. There was, however, a minority view that a crude stress on hands-on experience could mean missing out on the engagement of minds that they saw as crucial: 'perhaps we need more brains-on and less hands-on'. This might well be achieved through an initial focus on *pupils'* understanding of concepts.

> *Teachers started off scared; they thought they were going to have to reveal their own lack of understanding. When we looked at kids' learning in science, they cheered up no end. It helped them to realise there could be continuous development in the understanding of concepts to see the* ***direction*** *of change and recognise that there might not be one remote end-point they had to know about.*
>
> Science tutor

Longer, award-bearing courses

However plentiful and comprehensive the provision of short courses could be made, there should also be an expansion of longer award-bearing courses. Several staff pointed out to us that it was remarkable that in these times of teacher workload and stress, there appeared to be an increasing number of teachers interested in courses which were longer, more demanding, somewhat more theoretical and which resulted in a recognised award. There was a general pressure within the profession for increased 'credentialisation' – 'people see it as

more and more desirable to wave a bit of paper which shows they have something extra'.

Although such courses tend to satisfy deeper, long-term personal and professional needs, they should also be recognised as valuable in supplying people that schools will increasingly welcome – teachers who can act as curriculum leaders in some aspect of the curriculum and as supporters/consultants to their colleagues.

Staff saw the development of more certificate courses, such as we described earlier, as being highly desirable. There was clearly a place within these for a strong focus on teacher understanding of science and technology. Certificate courses in the teaching of science and technology in the primary school should be integrated into more comprehensive inservice award provision (Modular Postgraduate Award Schemes). The nation as a whole should have an optimistic vision of a primary teaching force in our primary schools increasingly leavened by primary teachers with MSc, MEd, MPhil and DEd qualifications in science and technology education.

Extra people into primary schools

Several people who talked with us, while stressing their faith in the quality of the existing generalist primary teaching force, argued that new and additional people were necessary in primary schools if the necessary breakthrough in science/technology was to be achieved. Such people might be education development officers from local authorities, advisory teachers, seconded secondary teachers or TEI tutors. Their role would be to work alongside primary teachers injecting into a co-operative partnership skills of classroom management for science/technology, knowledge of resources and materials and, importantly, understanding of content. The emphasis would not be on taking away some aspect of the teacher's role, but of supporting the teachers until they were confident and happy to continue on their own.

Whereas some stressed the injection of 'experts' of some kind, others said that importing *extra* people would be appropriate. They had in mind a person who could be 'an extra pair of hands', who would provide more time and opportunity for the normal classroom teacher to acquire confidence and experience, *ie* the teachers can become their own experts if some of the multiple pressures on them are reduced. Two people suggested a novel approach to this, as shown in this quotation.

> *It is a quite scandalous waste of the nation's resources that we currently train enthusiastic, high calibre young people to become primary teachers, then we don't employ them all – we force them out of teaching. These people could be mobilised into a National Task Force, to work as teacher-assistants. They might just be used as additional help in taking small groups; some of them could develop pupil activities and plan and prepare materials and resources ...*
>
> Science tutor

Networking within and among schools

We group under this heading all those recommendations by TEI staff that teachers can help and support each other by talking and listening to, by learning from, each other. All of these activities, of course, assume time is available and require the perception that the activities are valuable.

What did people mention? Teachers within one school exchanging information about good practices and ways of avoiding difficulties; teachers from a local cluster of primary schools coming together in informal settings; teachers from a secondary school communicating with teachers in associated primary schools; teachers networking by telephone; a 'helpline' from schools to friendly counsellors or subject experts in the local authority or TEI.

Although networking could be of very real general benefit, it was *essential* if there was to be any real success at the upper end of 5–14 developments.

> *Without genuine, purposeful primary/secondary liaison you can forget all about the P7/S2 stage and about progression. The network should probably be co-ordinated from the 1st end; too many secondary teachers have an attitude problem, the 'whatever you've done, we'll just start again and do it properly' syndrome …*
>
> Head of science/technology

Thus, TEI staff identified five general ways in which primary teachers could be helped to teach science and technology effectively – and which in different ways would assist the development of teacher understanding of science and technology. People did not, however, favour any one way forward.

> *I don't know which way would be best. We probably need a whole raft of helpful actions, of support strategies. No single way will work in isolation; try them all and somehow they may work in combination.*
>
> Science tutor

This view was clearly shared by the authority representatives we talked with. For example, the programme of inservice support in one region had the following features:

- a comprehensive programme of short courses – delivering science and technology in manageable chunks, in line with regional priorities and individual school development plans
- the identification of primary teachers with postgraduate awards in environmental studies/science/technology to act as reference people within cluster groups
- support to schools from visiting development officers
- encouragement of informal networking and 'neighbourhood' support from colleagues within the cluster group of schools.

A big push – or gentle growth?

TEI staff were divided on the scale of what is needed.

> *We have failed in the past to get a significant improvement on the teaching of science and technology in our primary schools; we cannot afford as a nation to fail again. A* ***massive*** *professional development exercise is needed both to develop adequate*

understanding in teachers of science/technology and to develop a battery of effective teaching strategies. We now have a framework; push has to change to shove. This will need a lot of money and energetic action by everyone.

Science tutor

You can't force people to do what they don't feel ready and able to do – all you do is get their backs up, or get the image of change without the reality. We have surely learned by now that science and technology are tender plants in primary schools; they need the gentlest encouragement to grow or they'll die off completely.

Science tutor

Views were not quite as polarised as these two quotations suggest. There was a middle view which expressed the need for a major national thrust (a National Training and Development Programme), adequately funded, taking place within the 5–14 framework we now have, but being carried forward at that very gentle pace which, given the necessary support, the teaching force could sustain without undue stress.

Another compromise view described to us was that the character of the initiative should vary depending on the people targeted: there should be an extremely vigorous overhaul of initial teacher training to have a relatively quick effect on those about to enter the profession; there should be very sensitive, gentle encouragement of mature members of the profession whose confidence in science / technology was lowest.

Education authority representatives were well aware of the extent of future need and demand for inservice support. The extent and nature of their response was going to be tailored to the availability of the necessary funds. They were finding long-term planning difficult.

Summary points about teacher education in primary science

Time given to science and technology in initial teacher education course

- Contact hours for science and technology in PGCE courses can be as low as 16/17.
- Contact time in the BEd is commonly about 80 or 90 hours over four years; in some cases it is much lower.
- The amount of science/technology teaching done on school placement varies very widely; for some students the amount is zero.

Emphasis or content or process in teacher education courses

- Courses try to serve a variety of aims, including both content and process.
- The emphasis on *content* (ie on student understanding of the ideas of science and technology) has recently started to increase and this is likely to continue – but there is opposition to the pendulum swinging too far away from *processes*.

Content and methods of courses

- Most courses in both science and technology are based on practical workshops, with a tutor introduction and summary.
- Content is organised in everything from 'small' topics (eg Water or Structures) to huge environmental studies modules (eg Europe).
- Increasingly course content is being structured to reflect the 5–14 Guidelines.
- A great deal is *not* covered; tutors hope students will come to understand these areas by their own self-directed learning.
- The need for differentiation is only now being seriously addressed in most TEIs.
- Most emphasis is on providing supplementary reading and on responding to student queries; both tutors and students are short of time.

The selection of students

- In the past the scientific background of students has not influenced their selection, but it is starting to have an influence.
- People are increasingly asking if science should become as important in selection as English and mathematics.

The role of optional elements of courses

- With some exceptions, science and technology options cater for only a small number of students. In recent years some science and technology options have been cancelled because too few students enrol for something they think may be difficult.

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Short courses and school-based inservice

- TEIs now provide few short inservice courses. The TEIs could not easily respond to a demand for much more; staff numbers in science / technology are low.
- Education authorities already provide many short courses and a variety of forms of school-based support. They are planning for a large increase in demand when environmental studies:science/technology becomes a priority. They anticipate the funding will be short and not budgeted over a long enough period.
- Short courses do not currently address the issue of teacher understanding (particularly of science) head-on; it is seen as an issue which will come to have greater importance.

Award-bearing courses

- The Postgraduate Certificate in Environmental Studies continues in five centres; increased demand is expected.
- The Postgraduate Certificate in Primary Science Teaching continues to flourish in one TEI and has now been set up in a second. It could be very important in future.
- At least two other postgraduate certificates are at the planning stage.
- There is increased recognition in (ii) and (iii) above that there is a need to increase teacher understanding of the concepts of science.

The challenge of meeting teachers' needs

- Adequately satisfying teachers' needs will need a comprehensive programme of staff development provision.
- Teachers' needs vary greatly from one individual to another; no one single response will be satisfactory.
- There is need for a multi-faceted response combining helpful teacher materials, short inservice courses, award-bearing courses, support in schools from visiting 'experts', extra hands in classrooms to release teachers' time and energy, and informal networking within and between schools.
- All of the above needs money and sensitive long-term planning.

5 The teachers who helped us ... 2

The teachers: six profiles

In this chapter are profiles of six teachers who helped with our research. We have written these for three reasons:

- to help readers see the subjects of our research as real people
- to pull together information about individuals who worked with us in Phases 1, 2 and (usually) 3
- to point out that if primary teachers are to be helped to teach science and technology effectively, then no one simple support strategy will suffice: different people have different needs.

Each of the people described is real; the data quoted are genuine. The names have been changed; no teacher who helped us had one of the names given here. The schools we describe are schools we visited, but they are not the schools in which the individuals taught. It may be that the teachers can recognise themselves, but we have tried to ensure that no-one else can identify them.

There are no men in the teachers portrayed. Given the relative numbers of male and female primary teachers, it would be difficult to justify the inclusion of more than one and foolish to risk the implication that all male primary teachers are similar to the one portrayed. We do not imply that all female primary teachers can be categorised into one of six types; we do, however, suggest (p191) a very rough frequency for the occurrence within the teaching force of teachers who are, in a limited number of ways, similar to the people we have chosen to portray.

Profile 1: Sheila Taylor

The building in which Sheila Taylor teaches her Primary 7 class is open-plan, attractive and modern; the headteacher claims that all the teachers say the building's design works well.

Sheila hoped to go from school to university and take a science degree, perhaps in microbiology. Unfortunately she didn't get the Higher mathematics she needed. She went to a college of education, with Higher passes in both chemistry and biology. After she qualified as a primary teacher, she worked for a while as a technician in industry and it was there she discovered her interest and abilities in problem solving.

> *I like getting my mind round any sort of wee problem. It's an intellectual challenge for me. How can I make something work? How can I adapt it for my classroom? I am not saying I am always successful...but I do enjoy the challenge of teaching science and technology.*

It's now fifteen years since Sheila qualified and she has been teaching for twelve of those years. She hasn't experienced any inservice provision specifically on

science and technology, although she did attend a three day course a few years ago on environmental studies, centred on 'The Whale'. She has a school role for co-ordinating Expressive Arts.

When she completed the Phase 1 questionnaire Sheila indicated that she was confident, or fully confident, about teaching most areas of the curriculum – including science and technology; the exceptions for her were music and religious education. She also said she was confident that she had the necessary knowledge for most of the contexts for pupil study we quoted from the 5–14 Guidelines (science and technology); the only exceptions were those most clearly concerned with physics or with control technology. She was also confident about her ability to develop science processes in her pupils and in her general teaching skills. In the Phase 2 interview Sheila also showed herself to be very confident about teaching science and technology; it was clear, however, that she thought that the confidence she felt was not shared by the majority of her colleagues.

She thinks that questions from the children are more difficult to answer in science; this doesn't worry her – she enjoys the challenge – but she thinks it does worry teachers who lack understanding of the content. History and geography are less worrying, because when you are asked a question, if you don't immediately know the answer you can look it up and what you find is instantly usable; however, in science, the questions are often about concepts and principles and even if you find the right ones in a reference book, you may well not understand them well enough to see how they should be applied in the particular situation that the pupils have asked about.

The three 'events' for which explanations were sought in the Phase 2 discussions were WATER, CIRCUIT and FISH. In the first two of these, Sheila showed her complete understanding of the big science ideas without any assistance from the interviewer. In FISH the first idea gave her no difficulty whatsoever; the second and third ideas engaged her attention fully; understanding was not immediately displayed, but with a very little prompting, Sheila showed a more secure and deep grasp than any other teacher involved in this phase of the research. The questions were not ones she felt she had been asked before, nevertheless, given minimum support, she came up with ideas that she herself found very pleasing. The understanding she showed in the technology discussions was similarly impressive. Sheila said quite spontaneously that she had enjoyed the interview; she had found the engagement of minds stimulating. She thought that the interviewer had the ideal job within education and was keen to discover how she could become an educational researcher!

Sheila's confidence about teaching science and technology came partly, she said, from her feeling of security in understanding the subject content and partly from having found a method of classroom organisation that worked well for her.

> *We do environmental studies for half a day every week. I have five groups in the classroom: one is doing historical research; one something geographical like mapwork; one is computer-based; the fourth does a topic about people in science and the history of science – like the work I told you about on Darwin; the fifth does either science activities or working with technology kits. At the moment one side of my classroom is given over to construction work with that German technology kit. Next week they go on to powering the vehicle they have made. After Christmas we'll move on to science*

activities. This time last year we did cold-water chemistry; the kit wasn't that good, but it introduced them to handling apparatus with safety, keeping it clean and so on. We worked with things like bicarbonate of soda and vinegar and universal indicator and we did a lot of reactions. No fancy formulae or anything – just handling things, observing carefully and describing what we saw. That's my way of doing things. I don't know if it's right or wrong according to 5–14 and I may have to change my approach in future...

When we talked to Sheila again a few months later, she had continued to do a lot of science and technology in this way; she had probably done more than any other teacher in our Phase 3 sample, but nonetheless she said that she was ashamed she had done so little, there was just so much pressure on the curriculum and so little time in her day to prepare additional science and technology activities. She was happy with the work of technology groups on the construction of powered vehicles; the only problem had been to ensure that everyone in the groups had been kept equally busy. An 'extra pair of hands' would have been helpful to allow her to spend more time with pupils who needed help. She had repeated the cold water chemistry activities and was 'very happy indeed' with this; the only problems were minor ones to do with equipment and materials: things would have been much easier with real test-tube racks rather than the improvised ones from yoghurt pots which kept toppling over – and it would have helped a lot to have more than one sink. Pupils had been fully occupied with doing things, looking at things and agreeing their observations; no pupil asked questions about 'the whys and wherefores', although Sheila said it wouldn't have worried her if they had.

Sheila wants much more science and technology done in primary schools; she wants young learners to know the excitement of these subjects and not to have their natural curiosity stifled by teachers who are not comfortable with being asked tricky questions. What actions does she think would be helpful?

(a) Ditch the 5–14 Environmental Studies guidelines – they are intimidating and unhelpful about science and technology. Instead give us a syllabus – a step-by-step guide with practical activities that really work, and appropriate equipment readily available.

(b) A massive amount of quality inservice training, from people who can focus on classroom organisation – not done by specialist scientists.

(c) Specialist help coming in to schools to build up teachers' confidence and understanding – rather like what has been provided for physical education.

Profile 2: Angela Douglas

The school building feels enormous – and empty; the school now has only a third of the number of pupils it was built for. Angela Douglas and the researcher talked in the corner of a chilly, unused classroom.

Angela qualified as a teacher twenty-five years ago and has taught for most of those years. The initial impression is of a woman who has life firmly under control; she seems confident, capable and highly competent; she has no science passes from her school education and she can't remember doing much science of

any kind in initial teacher training. She has never managed to attend any inservice courses (largely because of her heavy domestic responsibilities) of longer than half-a-day and none of the sessions she has been at has been concerned with science or technology.

In the Phase 1 questionnaire Angela said she was fully confident in all areas of the curriculum except science; she indicated that she could just about manage technology but needed a lot of help with science. In reply to questions 8 and 9 (content and processes of science) the majority of her ticks were in column 4 ('I need help to develop my knowledge and skills in this...') The questionnaire responses suggested that with regard to science (but science only) Angela was perhaps the least confident of all our respondents.

After the preliminaries to the interview, ARM was the first topic tackled. In response to the question 'How can we explain this? Will you start or shall I?' Angela insisted that the researcher start off, that she had nothing useful to say. As the discussion proceeded, she developed understanding of the ideas and visibly relaxed and regained her assurance. She was sure it would be very difficult for her to develop these ideas in pupils because 'I have no real background in biology'; she felt it would be easy for other teachers, because the ideas did not now seem all that difficult in themselves.

When the discussion moved on to CARBON DIOXIDE, Angela said 'I just don't know – you'll have to tell me'. When the interviewer started to talk of coal burning to form carbon dioxide, Angela's composure began to slip again.

> *I know it will seem silly to you, but I can feel the tears beginning to prick at the back of my eyes. I know this feeling well; it's just the same as I felt when I was at school, doing chemistry when I was about 13. I just didn't understand anything and I knew that I never would. I couldn't tell the teachers what it was I didn't understand. I just wanted to stop doing science as soon as I could...*

The interviewer then described how he had been reduced to tears at fifteen by the headteacher visiting the French classroom and quizzing him on irregular verbs. Angela and the interviewer agreed that the situation justified the consolation of illegal cigarettes; these were smoked in companionable misery – and a little anxiety lest the headteacher of this school visited this classroom. After this there was an extended attempt at collaborative explanation; Angela was sure her understanding developed not at all – and she was probably right. The ideas in this topic would be impossible for her to develop in pupils, she said, 'because of my block; I just have no grasp; I find all this impossibly difficult...'

Angela had completely regained her equanimity when the third topic MIRROR was introduced. However, she was able to offer no explanation of how people were able to see things and she developed no understanding of the other ideas in the topic. Again these ideas, she thought, would be very difficult for her to develop in pupils, because she herself had no understanding of what she described as 'physics-type concepts which are very difficult to put into words'.

She was hesitant at the beginning of MIRROR DEVICE, but suddenly decided that there were no difficult ideas involved and that she could just tackle this the way she tackled other projects This technological activity was thought by her to be much less likely to give rise to pupil questions that would 'throw' her. She

would provide the pupils with a selection of appropriate materials and they would get on with it; if the thing that they designed worked that would be fine – there would be no demands on her to explain **how** it worked. Any problems that arose in the course of pupil activity would be within her usual pedagogical expertise – they were unlikely to call on conceptual understanding that she didn't possess.

Angela obviously did not find the interview an easy and straightforward experience, but she did not let it throw her off her stride for long; she offered to help us again in the next phase of the research. When we spoke to her again some months later, she hadn't been able to do much science in the interim. A visit to a country park had been planned and then postponed several times; eventually the intended study of pond life was modified to become a lesson on the classroom goldfish. This had gone well until a pupil asked why some fish sink and others float when they are dead; if this question had occurred on the visit there would have been a Ranger on hand to answer it. As it was Angela just wished fervently that there was a telephone helpline for primary teachers attempting science topics.

Science is needed by pupils in primary schools, thinks Angela, and she doesn't want just to opt out. What support does she say she wants?

(a) *5–14 science should be scrapped and replaced by something achievable by those primary teachers with no science background, whose initial training gave them nothing very useful... Over the years I have been prepared to change; I have pored over books in the evening when I had plenty of other things to do – but this 5–14 is impossible; it is completely beyond the limitations of the non-scientific teacher.*

(b) *Inservice courses are unsatisfactory in an artificial all-adult environment. I need to* ***see*** *people teaching these things successfully to* ***real*** *children – I mean ones like you get in this area...*

(c) *If I could have extended help to become confident in one science topic, then I might have the confidence to try other things; especially if there was an adviser on the end of a telephone.*

(d) *I have a real block; in fact I have a fear of science; I need someone very sympathetic to help me.*

Profile 3: May Harrison

May Harrison teaches her Primary 6 class in a school building which is heavily Victorian outside and all light and colour inside. Although the building is big, it is also very busy; there are no empty rooms and little storage space.

May has no science in her own background. She has taught for about 25 years and is confident about teaching most things; she's had a lot of experience and has not only survived but flourished. She distinguishes between the confidence that a person gains from having their academic learning formally authenticated by experts and the confidence that comes from tackling something new and then feeling that you did a pretty good job. Secondary teachers, she says, ought to feel confident about their teaching because they are academically qualified in the subjects they have to teach; primary teachers on the other hand have to cope with

everything, and the spread of the curriculum seems to get ever wider and wider, therefore their confidence cannot simply depend on their academic qualifications. Primary teachers **become** confident by being interested enough to get involved and then finding it's not nearly as bad as they feared.

> *Once you have taught science, you're more confident about it. I've done it – so I'm not frightened of doing more of it.*

May's views on confidence are related to her general philosophy of teaching.

> *My aim is to get children motivated to want to find out for themselves; there is then less burden on the teacher trying to get them interested in learning; you don't need to be able to tell them everything...*

In the Phase 2 interviews, the researcher talked with May about WATER, FISH and CIRCUIT. Like most of our teachers May immediately identified the cloudiness on the side of the tin (in WATER) as condensation; when asked to identify the actual stuff she said it was dampness. She didn't think the stuff was just liquid water, rather she saw it as water in some kind of intermediate state: 'not quite a liquid yet'. Nor was she happy about the idea of water existing in the air as a gas; with prompting she showed understanding that air was a gas, but not that it was a mixture of different gases. When asked directly where the water on the side of the tin had been before, she rapidly produced a range of suggestions, but subsequently had great difficulty in evaluating the merits and demerits of her different ideas.

> *It's when you have two different temperatures and you get a reaction between the two of them, or perhaps the water on the outside came from the ice-cubes as they melted. It was perhaps a reaction between the hot air and the melting ice-cubes? Or it could just be coming through the sides of the tin?*

When asked why it might be that the water (as a gas) in the air had changed to water (as a liquid) on the side of the tin, May struggled very hard to find an explanation in terms of temperature alone. When prompted to think about heat or energy, she showed real puzzlement about there being energy in a gas.

It would be easy to list the concepts of which May seemed to have little understanding; they include – states of matter, change of state, mixture of gases, temperature/heat/energy, reaction.... However, despite the initial absence of some very basic ideas, the extent to which May started to grasp some of them in the fifteen minutes discussion was encouraging.

It is interesting to note that May did not think it was difficult to develop understanding of these same ideas in pupils.

> *You can show them solids and condensation; maybe gas isn't quite so easy – but you can get there by discussing it with them. As adults we are more,aware of the difficulties, so the ideas seem harder for me than they actually are for them.*

In FISH, May immediately showed that she understood that the observed differences in the fish were helpful in the different places in which they lived. She had no understanding of how these differences might have come about and developed none during the discussion. She was aware of terms like variation,

inheritance, adaptation, natural selection, evolution, but could attach no clear meaning to any of them.

May was pleased when we moved on to CIRCUIT. The concept of electrical circuit was familiar to her but, unusually, she was unclear how a simple switch worked – it had never occurred to her to wonder. The gap introduced in the circuit was pointed out and she then assumed that 'because there is nothing in the gap, the electricity can't flow'. The idea that it was difficult for the electricity to flow through the *air* in the gap was rejected because she was aware of recent publicity about the dangers to children of 'sparks from high-power cables'. She had always thought of a battery as simply giving out electricity; the bulb in the circuit was then 'worked by electricity'– it was not understood as a device which changed energy from one form to another.

Reflecting on this third topic May remained confident about her own understanding of the ideas.

> *I understood that electricity topic fine, because I have taught it recently.*

May seemed to believe that teaching something without any apparent difficulties not only increased confidence, but satisfactorily developed understanding.

When we talked with May again after a few months she hadn't done any more science teaching, but she said she had successfully introduced a design technology task into a European Awareness topic. Pupils had designed and built models of the Eiffel Tower. May was 'very happy' with this bit of teaching; the pupils had worked very well in their groups and showed themselves well able to suggest designs, to build, evaluate and modify their towers. The only problems were with a lack of storage and display space and a very restricted range of materials – she had made do with cardboard and sellotape. Science and technology equipment is not in generous supply and because of a shortage of classroom space is stored centrally.

> *But problems like these won't put me off teaching these subjects at all – they are just things I have to take into account.*

The changes she would recommend to make science and technology teaching easier for primary teachers are: classrooms appropriately designed for the modern curriculum and a readily accessed supply of materials, apparatus and kits.

Profile 4: Fiona Young

Fiona Young has a P7 class this year for the first time. The school in which she teaches was built to a rather conventional design only five years ago, in the same year that Fiona qualified as a teacher. The school seems big for the village in which it is centrally situated, but this is a village now surrounded by housing estates within easy commuting distance of a large city. The headteacher says the pupils cover the full range of abilities; the catchment area she describes as 'mixed tending to affluent'.

Fiona has no science qualifications from school. She thought the science part of her college course was interesting enough, but it was always possible to avoid

things you thought you wouldn't like or that might be difficult. She recalls she had to do some Environmental Studies during a school placement; she managed to make it look as if there were science and technology aspects within the teaching plan for her topic – but she never actually taught these. She doesn't remember doing any technology at college at all; this is why she recently asked to attend a couple of single day inservice courses in teaching technology. A colleague has done a postgraduate certificate course in teaching primary science and has recommended it to her. Fiona thinks she may enrol in this when Environmental Studies has a higher priority in 5–14 implementation.

In her answers to the Phase 1 questionnaire she said she was fairly confident about teaching most areas of the curriculum, but she lacked confidence with science and technology. In her answers to questions 8 and 9 (content and processes of science) almost all of her ticks were in column 3 ('I can manage but depend on advice from others') with a few 4s in aspects of physical science ('I need help to develop my knowledge and skills in this area'). Overall her replies certainly did indicate a lack of confidence in teaching science and technology, but Fiona was by no means the least confident of those teachers who helped us in our research.

At the beginning of the Phase 2 interview, Fiona made clear her attitude towards science.

> *That's the one area where I think 'Science – ugh; I suppose I have to do it'. It just doesn't come naturally to me, but that doesn't mean I don't do it...*

FISH was the first topic to be discussed. Fiona quickly demonstrated her observational skills by giving a clear and lengthy list of the differences in the two fish and convincingly related these to the different environments in which the fish lived. She hesitated a little on how these differences had come about and then showed her understanding that chance variations within a population could be inherited; she had some difficulty, as did almost all of our teachers, in seeing how natural selection of variations helpful for survival led over time to evolution.

When the researcher moved on to CIRCUIT, Fiona had no problems of any kind in explaining all that was observed; she showed clear understanding of the big science ideas and revealed no misunderstandings or misconceptions.

The third topic was WATER. The first two of the underpinning ideas (that water exists as sold, liquid and gas and that the cloudiness on the cold surface of the tin was liquid water that had come from the water as a gas in the air) gave her no difficulties at all. She was happy to talk abut differences in temperature, but didn't initially see how to explain changes of state in terms of energy; when prompted, however, she easily took this on board and went on to consider its teaching implications.

> *I did all this with P6 last year and never mentioned energy. I'd never thought about the changes in energy terms and I'm not sure whether I would introduce that concept at this stage. Energy is difficult for pupils; they tend to think of it only as something that they have – to run about and do things....*

The interviewer asked Fiona why she lacked confidence in teaching science when her understanding of science ideas appeared so sound.

> *Science and technology worry me more than any other areas of the curriculum, because the children may well know more than I do – so when I teach, I tend to stick to what I know. But actually it's amazing how much you do know. I didn't think I knew anything about science, but if you think about it in terms of the classroom, you say 'Och aye, I did the water cycle; and then I did this and a bit about oil and energy' so when you put it together you do do a lot; you know a lot more than you first think you did.*

Fiona may claim to stick to what she knows, but when we spoke to her later in Phase 3 she had embarked on a series of new lessons about propulsion and submarines (to tie in with her World War II topic) and on a programme of technology activity about the design of oil rigs. Although there were a few occasions when she felt she didn't have enough knowledge to address children's problems and advance their learning, she said her main problem had been the lack of someone to look after equipment and to see that everything was working properly.

> *I need a technician like they have in secondary schools.*

In her technology work on oil-rig design she also had problems obtaining some very simple materials, because of financial constraints. The design of the school, the availability of different working areas, and a good supply of sinks, all helped her in managing practical activities.

Profile 5: Jean Auld

The late '70s building, 'a school without walls', won a design award, but the teachers don't think much of it. The school is overcrowded; there is no spare teaching space and remarkably little storage room. There is no privacy of any kind: 'If you're having a bad day, everyone knows'. It doesn't seem likely that Jean Auld often has a bad day; she seems young at heart, strong, capable and humorous. 'Why did the architects not know that children come in different sizes? They should experience what it's like with my thirty large 11/12 year olds.'

Jean did some science at school, but nothing beyond O Grade 'and that was a very long time ago – nearly thirty years'. She liked science at school; she has been to a lot of short inservice courses since she qualified, including some on environmental studies, but didn't like them much.

In the questionnaire in Phase 1, Jean came across as pretty confident about teaching all curriculum aspects, including science and technology; only in Art and Music did she feel she needed more than a little guidance. Most of her responses about aspects of science and technology displayed confidence as well; there were only two exceptions out of the list of 26 items; potential/kinetic energy and the use of control technology. She was confident about science processes and more general teaching skills, although she admitted to some difficulty with assessment and recording. Overall, she was more confident than most.

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In the Phase 2 interviews, Jean's grasp of the big science ideas was impressive. She displayed complete understanding of the concepts involved in the explanation of ARM movement, actually going beyond any expectations of ours in explicating that work is being done whenever a force makes something move. In CARBON DIOXIDE she hesitated a little over her first account of 'burning'; she then came out with the statement that 'coal is a complex mixture of carbon compounds and when you heat it, the components are separated and released' which rather suggested she was remembering an experiment from her school chemistry about the destructive distillation of coal in the absence of air, ie there was a little confusion in her mind between this and burning. When this was tentatively suggested, she immediately put things right. The other key ideas were clearly used in a way that showed secure understanding; she was one of the few who handled the third idea (it's easier for light energy to go in, than heat energy to get out again) with accuracy and without any input from the interviewer. In MIRROR, Jean immediately showed understanding of the role of light in seeing things; she paused for a little in thinking through the path of light as it was reflected off the mirror, then reached understanding very rapidly. She then volunteered additional understanding again: 'I'll explain to you why the dinosaur is green, if you want ...'. Jean's understanding of science ideas was high and she showed a striking ability to think quickly and then express her conclusions in very clear language.

Jean was quick to acknowledge the little contributions made by the interviewer.

> *It was good that you clarified that bit. I suppose I already knew, but your questions helped me reorganise my thoughts ...*
>
> *I've really learned something from that ... it will help me, if I have to explain it to the children.*

Jean was one of the many teachers who insisted that before teaching science she would always try to do some reading in preparation; she was less typical in that she didn't worry much about pupils asking difficult 'why' questions.

> *My normal practice is to research science topics beforehand. I don't ever try to teach science off the top of my head; I always feel I need a bit more background knowledge. It does mean rather a lot of scanning through books. If I don't know something, I have no difficulty in admitting it; I'll tell them I don't fully understand. I think it's a good thing for the children to know that teacher doesn't know everything, but she'll try to find out. I don't feel there's any need to be hung-up about that.*

When we spoke to Jean in Phase 3 she had done quite a lot of both science, and physical science at that, and technology teaching. She had tried a topic quite new to her, Pulleys and Levers; unhappily, equipment newly-ordered from a catalogue had turned out to be inappropriate for her class – the materials were too fine and small-scale and when they didn't work, she couldn't put things right. She distinguished between understanding an idea and understanding why things work: the two are not necessarily the same.

Jean was positively looking forward to having to teach more science and technology when 5–14 Environmental Studies really got going, given appropriate support: 'I like dabbling – that's why I came into primary teaching; the variety of subjects still appeals to me'.

What support would she like?

- More room – to do things and to store things.
- Inset courses giving hands-on experience.
- A package of materials on 5–14 and a school policy on what to teach when.
- Increased liaison with the secondary school with the chance to share resources and equipment.
- The opportunity to be an apprentice, particularly in technology.

I'd love to spend a couple of weeks with a beginning teacher who had specialised in technology; one of those bright young things who's really into this in a big way; and to help them … see the ideas in action in a real, practical classroom-type situation with other groups going on. And I think once you'd seen it working – and how it can really take off then you'd know 'Yes, I can do that …'.

Profile 6: Lorraine Campbell

The school was built in the early '30s; it's a handsome, single-storeyed building arranged around a central quadrangle – the classrooms are light, airy and cold in winter. The school is now somewhat under-occupied, there are vacant classrooms available, plenty of 'nooks and crannies' and no problem over storage space. Lorraine doesn't teach a lot of science and technology to her primary 6 class, but recognises she has no problems over space for a variety of activities; there are plenty of materials and resources, well stored and easily accessed.

Lorraine has an O Grade biology; she went into a Higher biology class at school, but was not presented for the subject; she has no other science qualifications.

There are some aspects of science I am confident in; I took biology at school, so therefore any aspect which involves that I'm perfectly confident in; but when it comes to physics, forget it. I have no training, no education and I've had no help as a teacher.

This kind of picture is clear in the questionnaire responses; Lorraine recorded that she was relatively confident in science overall and lacking in confidence in technology and information technology. In all the key features relating to biological topics she ticked box 2 ('confident with a little guidance'); in all those relating to physical science she ticked box 4 ('I need help to develop my knowledge/skills'). She was more confident in helping pupils develop the processes of science, and very confident about her general pedagogical skills.

When discussing CIRCUIT with us, Lorraine readily confessed 'I haven't a clue – this is where I fall down'. Her understanding *was* weak. She said she knew that positive and negative were important, but not why and she tended to explain situations where the bulb did not light with 'the pluses and minuses are wrong, somehow'. The concept of 'circuit' was absent, and not established or developed during the conversation. She was unable to interpret any of her observations in terms of energy.

Like almost all teachers, Lorraine was quite clear about the differences in FISH being related to where they live. However, she was unable to make use of the other big ideas in this topic. There was a clear misconception in her use of an

example to illustrate evolution: 'it's just like the tadpole evolving into a frog'. When we were talking about natural selection, she produced the novel hypothesis that 'the slow-looking flat fish has grown to be like that because it's lazy'. Interestingly, Lorraine's own diagnosis of her understanding was very positive; she said she had understood all the big ideas at the beginning and her understanding hadn't been prompted to develop in any way. Lorraine thought that the ideas in this topic would be easy to develop: 'because they are very interested in things like this, it's not difficult at all to teach'.

In WATER, Lorraine clearly understood that water can exist as solid, liquid and gas; condensation was said to be the *product* of water changing from a gas to a liquid. When asked to interpret the process of condensation in terms of energy, she was unable to contribute at all, 'Oh dear – that's physics ...'. However, Lorraine's reflections on her own understanding were positive.

> *I understand this, because I've taught it to the pupils; I didn't need the energy bit – so my understanding of that was never required.*

Lorraine was quite clear about the science she would be happy to teach; her major worry was the way her teaching of science (and technology) was likely to be perceived by secondary school teachers.

> *... simple things, which pupils can actually observe; where they can come to conclusions from watching things. But if you have to explain things, that means getting into particles and that should be secondary science.*
> *I find that secondary science teachers actually object to primary science, because we are not trained specialists; they feel we're going about it the wrong way – when kids go up to secondary, they'll have to unlearn their wrong ideas.*
> *I really think they throw money at secondary schools and forget about us – and yet we are supposed to be able to teach everything. We've got to be specialists in all subjects; that's asking an awful lot, especially when you don't get the backing or the resources.*

Lorraine said she had enjoyed talking to us; it was good 'to get a lot of things off my chest, to someone who listens'. She did, however, feel that she had been 'volunteered' by her headteacher to take part and had not felt free to say no. Because of a very heavy workload, she would prefer not to take part in Phase 3 of the research. Her parting words were 'Make sure you get someone out there to listen to folk like me ...'.

■ Six teachers – what of the others?

Profile 1 Sheila Taylor has quite a lot of science in her background (two Highers); her confidence about teaching science/technology is high; her understanding of science ideas is high (or deep?).

Profile 2 Angela Douglas has no science in her background; her confidence about teaching science/technology is low; her understanding of science ideas is also low.

Profile 3 May Harrison has no science in her background either, her confidence about teaching science/technology is high – but her understanding of science ideas is low.

Profile 4 Fiona Young has no science in her background and her confidence about teaching science/technology is low; however, her understanding of science ideas is high.

Profile 5 Jean Auld has a little science in her background (O Grades in chemistry and biology); her confidence in teaching science/technology is high and her understanding of science ideas is high.

Profile 6 Lorraine Campbell also has a little science in her background (O Grade biology); her confidence about science/technology teaching is very mixed – it is high on anything biological and low on physical science and technology; her understanding of science ideas is generally low.

These are six real people, but suppose we were to suggest that they represented six broad categories of female primary teachers in Scotland. How commonly would female teachers fall into the six categories? This is, of course, a methodologically dubious exercise: we have to make somewhat arbitrary decisions about what constitutes a lot and a little science in the background, where low confidence is to be distinguished from high confidence and where low understanding is distinct from high understanding. Real people occur all along such dimensions and not just at the polar extremes; decisions at the cut-off points are going to be unreliable. In addition, we can only attempt such an exercise for those 34 female teachers who completed the questionnaires in Phase 1 *and* who were interviewed in Phase 2, we do not have enough information about the others. All these caveats notwithstanding, we give the results of such an exercise in the table below. We can reasonably claim that these 34 are not hugely different from the female primary teaching population in general, but to generalise to percentage occurrences of 'types' in that population would be bold and hazardous.

Table 5.1: *The numbers of female primary teachers in different categories (N=34)*

	1	2	3	4	5	6
Science in background	A lot	None	None	None	A little	A little
Confidence about teaching science/technology	High	Low	High	Low	High	Mixed
Understanding of science ideas	High	Low	Low	High	High	Low
Number in this category	6	12	6	4	2	4

There are a number of comments to be made on the above; these should be related to what we said in the closing sections of Chapter 4.2.

- When teachers have some science in their background, they always have at least some confidence about teaching science. None of our teachers with some science were in the group of teachers with lowest confidence. (Lorraine had biology and was confident about teaching biological aspects; she had low confidence about the science areas she had no qualifications in.)
- When teachers have some science in their background, they may *not* have a high understanding of all the science ideas that pupils are expected to understand. (As a very rough rule of thumb, O or S grade seems not to guarantee adequate understanding, whereas Higher usually does.)

The number of teachers with some science in their background is increasing, ie younger teachers have more science than older ones. (There have now been three years of intake to BEd courses of students for whom some science was compulsory to Standard Grade – a requirement for pupils entering S3 in 1988.) This will increase confidence about teaching science; it will not guarantee adequate understanding of important science ideas.

- There are teachers with no science in their background who are confident about teaching science, but whose understanding of science ideas is limited. In other words, it is possible for confidence to be somewhat misplaced.
- There are teachers with no science in their background, whose confidence is low – but who have achieved understanding of key science ideas. In these cases the lack of confidence may be thought somewhat unjustified.
- There are teachers with no science, low confidence and little understanding; there are a significant number of teachers like this. (Angela's case is more extreme than some, but she is very far from alone.)
- There are combinations of characteristics which do not appear in this table; they did not appear within the 34 – but they may well exist in the teaching force. They include people with a lot of science background, but low confidence, and people with no science but with high confidence about teaching science and high understanding of key science ideas.

We have not portrayed any male primary teachers in this chapter for the reasons given earlier. However, it would be wrong to create the impression that we do not care about the men or have nothing interesting to say about them.

There were two men who both completed Phase 1 questionnaires and Phase 2 interviews. Both of these would fall into the same category: a little science in their backgrounds (O grade), high confidence and high understanding.

John says that 'although I have a little science from years back, it isn't necessarily enough to teach science at primary level; you have to understand it well enough to be able to make it digestible for pupils'. The major problems for him, however, are not really to do with understanding or confidence but (a) in managing a class of 26 doing practical activities and (b) trying to find the science and technology opportunities in projects where they don't obviously occur.

Scott claims a good knowledge of science gained through his personal reading over the years. However, he doesn't see a lack of content knowledge as any impediment in his teaching.

> *I'm quite happy to say 'Sorry, I don't know the answer to that question, where can we go and find out?' I don't pretend to be a know-all. You've got to be positive about it and say 'Right, let's go from this not-knowing situation to finding out. Let's do it together ...'*

It may be recalled from Chapter 2 that of the 57 teacher interviews that were begun, 55 were completed in accordance with the collaborative explanation strategy. The only two not completed were with men; these men were happy to talk about the general challenges of teaching science and technology but were unwilling to examine their own understanding of ideas. These two men *had* indicated in the Phase 1 questionnaire that they were lacking in confidence about

their knowledge and understanding.

Male primary teachers are on the whole more confident about teaching science and technology than are female primary teachers; however, there *are* men who lack confidence and they are as deserving of support as people of the opposite sex. They may be more defensive, or more assertive, than women; it may be more difficult to assist them.

In this section we have begun to move beyond findings to issues and implications. This process continues in Chapters 6 and 7.

6 Some Key Issues

From the range of issues relating to the teaching of science and technology in primary schools that have emerged in this research, we have chosen to focus here on seven which we believe to be particularly important. The seven are not discrete and certainly overlap:

- Primary teachers' confidence – is there a problem?
- Primary teachers' understanding – is there a problem?
- What level of understanding is necessary?
- How are teachers' confidence and understanding related?
- What effects do low confidence and low understanding have on teaching?
- How should initial training be changed?
- What professional development of teachers is needed?

■ Primary teachers' confidence – is there a problem?

What does it mean to be confident? The word suggests approaching some task with a degree of self-assurance. People with confidence are likely to be reasonably successful; they probably won't have to call on someone else to rescue them; when the task is completed they will feel satisfied about what they have done. Those with confidence are fairly sure that they have whatever skills and knowledge are needed to achieve what is intended. Confidence is thus a positive feeling based on self-appraisal of skills and knowledge possessed.

To be confident does not mean that it is anticipated that there will be no problems of any kind; challenges are expected, but past experience leads confident people to think that they will be able to meet the challenges. Total confidence would probably mean either arrogance or a lack of imagination or both. Some feeling of anxiety is normal, stemming from insight into the complex demands of a situation, and may well be necessary to perform effectively in any new context. However, just as there is a level above which anxiety becomes disabling, so also there is a level below which confidence should not fall.

This research shows that in Scotland, primary teachers' confidence about teaching science and technology is less than for almost all other curriculum aspects. Within this broad statement there are clear differences: primary teachers express more confidence in their ability to teach about living things and the processes of life than they do about energy and forces; they are more confident about social aspects of technology than about control and design technology; they are more confident about developing science processes than about developing understanding of science content; they are more confident about their general non-subject-specific pedagogical skills than about skills relating to science and technology. Male teachers are more confident than females; the more recently

qualified are more confident than the longer qualified; those with substantial amounts of science in their background are more confident than those with less or none. All of these things are confirmed in the Phase 1 findings.

The interviews with teachers allow us to say more about some of the influences on confidence. The experiences of some in secondary school, as learners of science themselves, have been negative and aversive; the majority of primary teachers are women and they are likely to have been affected by some form of gender bias encouraging the perception that physics and technology are 'male' subjects. Science and technology will probably have been given little time in initial training and the approach adopted may have failed to arouse enthusiasm. Inservice training may have been difficult to find, or not sought, or if sought not felt to be confidence-enhancing. Many teachers feel that their professional remit is now being unreasonably extended to cover curricular areas they have previously preferred to avoid; many are somewhat weary through innovation overload and feel that science/technology could be a last straw which will break their usual well-founded feelings of confidence in their professional effectiveness. Others have an acute awareness of the real difficulties of teaching these practical subjects and assess the level of support and the quality of available resources as likely to be inadequate.

Does all this add up to a serious problem? Obviously in one way it does. Ideally all primary teachers would be approaching the tasks of teaching science and technology with a keen sense of anticipation, secure in their personal confidence that they are about to do a first-class job for their pupils and soon to feel that warm ego-enhancing glow of a tricky mission successfully accomplished. Manifestly the majority of teachers do not feel at all like this. Many teachers think that there is a problem; many teachers think that they themselves *have* a problem. They are not all wrong.

It is, of course, quite possible that people in the education system other than the primary teachers themselves will not share the teachers' view as to the seriousness of the problem, or of all aspects of the problem. The teacher who says that s/he hasn't taught much science and technology yet and feels a lack of confidence about the prospect of having to do more can be told that such feelings are only to be expected and that once they do get involved confidence will grow with experience. Teachers who confess that when they read through the science/technology guidelines all their confidence evaporates might be reassured by the recognition that this is a natural reaction but that they will have help from a school policy, from colleagues, from classroom materials and from their own general expertise in teaching. Some teachers admit they lack confidence in their own understanding of the concepts of science and technology; to which the retort may be that they shouldn't overestimate how much young learners have to come to understand and surely they, as adults, can find the time to fill in whatever gaps exist in their own understanding? Other teachers say that they lack confidence in their ability to manage groups doing practical work, with apparatus that isn't very familiar or reliable, while keeping all other pupils gainfully employed at the same time; but they are experienced teachers with well-developed classroom management strategies – they should trust in their own abilities – they will cope.

There is, however, a problem about teachers' lack of confidence in teaching science and technology and others should not just dismiss it as temporary,

unjustified or a mere fact of life ('no-one ever said it would be easy...'). The nub of the matter would seem to be that this lack of confidence is a fear that they are not going to do a good job; and insofar as they base this on an accurate perception that they do not have all the necessary understandings, they are right. the job they do will not be as good as it could, and should, be.

The majority of teachers *will* cope and their confidence *will* grow. Some will cope at considerable personal cost and some will cope at the expense of quality of pupil learning. There are a number of teachers – we do not know how many, although we hazard estimates later in this chapter – in whom a severe lack of confidence could pose serious problems.

It is not acceptable for any developed educational system to write off even a minority of its teachers; people are far too valuable a resource for that. And although the remainder will cope, there is no doubt that their performance and well-being would be greatly enhanced by an extensive provision of professional development opportunities sensitively tailored to an analysis of needs. If teachers' morale falls below a certain level, the quality of teacher/pupil interaction suffers and so does the quality of pupil learning. It is vital that young Scottish pupils have an enjoyable and informed introduction to the pleasures and demands of learning in science and technology; they deserve it and the nation cannot afford it to be otherwise.

■ Primary teachers' understanding – is there a problem?

Reference was made in Chapter 1 to some HMI reports and some research that had indicated there was a problem with respect to primary teachers' understanding of science. Does our research confirm this? Things are rather different with respect to science and to technology, so in this matter we deal with the subjects separately.

Science

We looked at teachers' understanding of six topics derived from the 5–14 science guidelines and at eighteen 'big science ideas' useful for explaining what might be observed within these topics. The topics and ideas were carefully selected, but they represent a small fraction of all the science that the guidelines recommend for pupils of primary school age. We concluded that it makes very little sense to talk of teacher understanding at the level of topics; a topic is as easy or as difficult to understand as the ideas that are defined as being necessary within it. The big science ideas identified varied widely in the extent to which they were understood by teachers; one idea, for example, was securely understood by every teacher we interviewed; another was understood by no teacher initially and only by a quarter of them after discussion of the idea during the interview. Individual teachers varied widely in the level of their understanding across the ideas; one teacher clearly understood all the ideas discussed, another showed understanding of less than half of the ideas even after discussion. Thus there are teachers who do not understand the science ideas that the 5–14 guidelines expect them to develop in their pupils; there are teachers who possess some of the same misunderstandings as do their pupils. Development of understanding of some ideas took place rapidly with some teachers during brief discussion; understanding of some other ideas developed much more slowly and less frequently during the time available; some misunderstandings were simply cleared up, others would take much more

time to change. (These findings are presented in detail in Chapter 4.2 with discussion of what seems to make some ideas easy to understand and others much more difficult.) Possessing some science in their own educational background made understanding of the big science ideas more likely – but it did not guarantee it. Also there were teachers with no formal science in their background who had somehow managed to gain a good understanding of the science ideas that we considered.

Whether or not this all adds up to a serious problem is a matter of judgement. This can be illustrated by two examples. In each of these we make the same two assumptions that the level of understanding in teachers as a whole will be much the same as in our sample of teachers and that the big science ideas we worked with are a reasonable sample of all the science ideas that might be derived from the 5–14 guidelines.

Firstly, consider a stringent judgement of what might be required. Suppose we expect all primary teachers to be able to demonstrate understanding of all the 5–14 science ideas without any preparatory study. Then, with this demanding idea of what constitutes mastery, probably about 26 in every 27 teachers do not understand the science ideas they are to develop in pupils; this means about 21,500 teachers. The problem is enormous.

Secondly, consider a generous judgement of the situation. Suppose we agree that the most difficult third of the ideas used in this research are beyond what primary pupils should be expected to come to understand – and that this would apply to all the big science ideas that might be derived from the guidelines. Suppose, also, that all primary teachers will demonstrate understanding of the remaining two thirds of the ideas after a little discussion with a knowledgeable colleague, or perhaps after some preparatory reading. Then, probably about 23 in every 27 teachers have the potential to acquire the level of understanding of science ideas they should be developing in most of their pupils. This means there will be about 3,300 primary teachers in Scotland who cannot. In other words, the problem is not that great.

If, instead of the researchers' inferences of teacher understanding from interview data, we take the teachers' own views as expressed in the questionnaire then, as we show later (p207), about 60% of teachers need help with at least some aspect of their understanding; this is about 13,400 people. This includes a quarter of teachers (some 5,600) who need considerable help.

It may be argued that focusing in this way on the understanding of science ideas, i.e. on the content of science alone, exaggerates the extent of the problem. Surely if most teachers appreciate in some general sense the *nature* of scientific investigation, then they can engage pupils in enjoyable science activities? There are at least two points that have to be made in response. Firstly, the processes of scientific investigation must operate on some scientific content; investigation both requires scientific understanding and develops it – it cannot occur in a content vacuum. Secondly, the 5–14 guidelines make it quite clear that pupils have to develop understanding of science. It may have been possible (for both pupils and teachers) to get away with minimal understanding of science concepts in the past; the policies of the 5–14 programme will not allow this in the future.

Technology

There are several aspects to consider. Some significant numbers of teachers do not have a secure understanding of certain ideas in science; when technology involves the application of those ideas, then the application will be flawed or misconceived. However, when technology involves understanding dependent on 'the common-sense of everyday experience', then teachers frequently possess that understanding. But the life experience of primary teachers is as varied as that of other intelligent lay-people and such understandings cannot be guaranteed.

In teachers' technology there is a common tendency to focus on a product or artefact rather than on the processes of arriving at the product, indicating a lack of understanding of the nature and aims of technological education. In some cases the main problem is in the expressions used to convey ideas of technology but in others it is much deeper.

Teachers often lack the standard vocabulary of the design process, but the ideas to which that vocabulary refers are quite often familiar; these ideas are not seen as difficult. Many teachers are unfamiliar with the language of control technology and many have a lack of understanding of its concepts.

Although in the Phase 1 questionnaire more teachers said they needed help with their understanding of technology than of science, in our Phase 2 interviews teachers thought that the ideas of technology were on the whole easier and less difficult to acquire. This may well be because in Phase 1 teachers only had the words to judge from and react to, whereas in Phase 2, they *saw* what was meant and they recognised it. Later in this chapter (page 207), we suggest that perhaps 60% of teachers need help with their understanding of technology and perhaps 30% need a lot of help. These figures stem from teachers' *own* views on the help needed. It may be that the help is needed to understand the concepts of technology and technological education, rather than the understanding of concepts applied in technological activity.

The recent publication of a Framework for Technology Education in Scottish Schools (SCCC 1994) should help primary teachers to know and understand what technology means and what the purposes of technology education should be. It is interesting that this document refers to the 'base of technological concepts' that is needed to define technological capability in pupils. We think it would be helpful to clarify the extent to which there is 'content' for technology in the same way as there is for science and to define those concepts which make up the technology base. Further research would then be necessary to gauge the extent of the problem caused by a lack of teacher understanding of those technology concepts.

■ What level of understanding is necessary?

What we have said so far has been based on the ideas that teachers are to develop in pupils. It could well be argued that teachers' understanding should be much deeper than intended pupil understanding. The official view is that teachers should have a knowledge of their subjects (ie in this case of science and technology) 'that goes beyond the immediate demands of the curriculum' (SOED 1993c). How far beyond? We approach this first from a theoretical and then from a pragmatic perspective.

A theoretical perspective

It has long been a part of the conventional wisdom of teaching that the experienced teacher can teach adequately if s/he is 'two pages ahead of the pupils'. Although this embodies an unhelpful metaphor for learning (that it is some kind of linear process of content coverage), it does at least contain the sensible idea that the teacher-as-expert is not someone who has already arrived at some remote destination on the frontiers of knowledge, but is a fellow-explorer a bit further along the path. As one of our teachers put it, she needed to feel that she was 'two jumps ahead of the pupils cognitively'. If the aim is concept development rather than mere content coverage, it is necessary to re-interpret the 'two pages ahead' requirement.

Phase 2 of this project was based on a particular view of science in the primary school – that it was centrally concerned with observing objects and events in the natural world and with trying, through investigation, to find satisfying explanations of what was observed. Understanding (in this case of big science ideas) was taken to be a personal construct that could be inferred from what was said during attempts to explain. We can take each of the events featured in our interviews and see them as underpinned by a structure of explanatory statements all at different depths. Suppose that for a particular phenomenon, ideas a and b, at a very simple level, constitute the kinds of explanation that would be accessible to and satisfying for P4 pupils; idea c might be somewhat more satisfying – it would be the kind of idea that you would give to someone who asked 'But why...?' when offered idea a as an explanation. Idea c might thus be appropriate to and satisfying for the majority of P7 pupils. We could track these explanations further to bigger, more abstract and more general ideas. These might be about atomic structure, big molecules, entropy and so on. At even more profound levels we would reach the fundamental theories of quantum mechanics and general relativity. The more general the idea the more widely applicable and the greater the number of different specific ideas embraced.

Research into primary pupils' thinking (eg Osborne et al, 1990) shows that one of the main characteristics is the lack of overall structures; the pupils do not have ideas which link one phenomenon with another in the way that the scientist would see them as related. For example, pupils may successfully wire a bulb into a simple circuit but not be able to connect another device, such as a motor, also having two connections, into the circuit. Progression in pupils' ideas comes through helping them to make links in their minds between related ideas. To do this a teacher must recognise these links, ie must possess the more general idea which links the separate ones. As we have just said, these more general ideas can, in turn, be linked to form more encompassing and abstract ones. Just how far it is necessary to go is not easy to say in general terms. Primary teachers do not need degrees in physics, chemistry, biology and design, but they need to be able to deal confidently with pupils' questions and to lead them to make the links which constitute progression in understanding. Of course they won't be able to answer all the 'why' questions – nor should they try to; the teacher aiming to be able to answer all such questions would be guilty of assuming that understanding can be transmitted to rather than being developed in the learner.

The big science ideas at different levels of generalisation could be identified for all the 'foci of study' specified in the 5–14 guidelines. Such a mapping would

illuminate both the ideas of progression in conceptual development for pupils and the level of understanding it is desirable to aim for in the initial and inservice training of teachers.

A pragmatic perspective

A pragmatic answer to the question of what level of understanding is necessary might be that those who wish to teach science and technology in the primary school should themselves possess qualifications in science and technology from the secondary school. Younger teachers have more science in their educational backgrounds than older teachers; the proportion with science in their background will increase naturally over the years. Young entrants to the teaching profession have, since 1991, all studied some science in secondary school up to S4.

However, the research seems to show that the fact of possessing one Ordinary or Standard Grade pass in a science subject may have had a significant effect on teachers' confidence about primary school science and technology teaching – but it did not guarantee understanding of all the ideas desirable for that teaching. There is nothing surprising about this: a pass in Standard Grade Biology is unlikely to help much with the understanding of basic ideas in physical science; it is possible to gain a pass in Standard Grade Science, for example, without secure understanding of all the ideas that one is meant to have encountered. Therefore, if we were to suggest a revision of the entrance qualifications for primary training courses, it would be that all candidates should have, as a very minimum , two Standard Grade passes in science subjects; it would be preferable to raise the requirement to one science Higher pass in one of biology, physics or chemistry and a Standard Grade pass in the other two.

We feel unable at present to make any similar recommendations for technology, for a variety of reasons. Technology in primary schools can benefit from people with a wide range of approaches and qualifications; we could argue for entry qualifications in art and design, technical subjects, home economics and social subjects. The most difficult concepts within technology are those derived from science, thus increasing the base of science knowledge should have a desirable effect on technology understanding. However there are concepts relating to technological processes which are less easily identified with a particular subject.

To say that the level of understanding required in primary teachers should be the level assumed to be gained in secondary science qualifications may be relevant for new entrants; it does little for the majority of serving primary teachers. As adults, their subject understanding is not often increased through Standard and Higher Grade courses – although for a few this might be the route of choice. There are more focused, productive and economical routes to understanding than this.

How are teachers' confidence and understanding related?

There is a simple common-sense expectation that confidence and understanding will be positively correlated, after all one component of confidence is the perception that necessary understanding is possessed. In Chapter 5 we reported on the confidence and understanding of the 34 female teachers who had helped us in both Phases 1 and 2. Sixteen of them were low in both confidence and

understanding; eight of them were high in both confidence and understanding; in other words perhaps 24 out of 34 fulfilled the simple expectation. The correlation is not perfect; the exceptions are important and interesting.

There were a few teachers whose confidence about teaching science/technology was high, but whose actual understanding of the science/technology ideas was low. Their confidence about teaching in the science/technology areas of the curriculum seemed to flow either from a kind of holistic awareness of their general confidence as teachers or from the assumption that doing some kind of science course at secondary school had inevitably provided them with the understanding necessary for primary school teaching. Equally important are those few teachers whose confidence was low (stemming often from the absence of any, or any positive, experience, of science from their own schooling), but whose understanding of science ideas was high. It may be that, aware of some deficiencies in their subject understanding of what they were planning to teach, they had taken steps to remedy them by personal reading and discussion with friends and colleagues or that they had acquired understanding incidentally through their general curiosity and life experience.

There can be no easy assumption that confidence and understanding always go together; often they do, but teachers exist whose confidence is somewhat misplaced and conversely there are some whose lack of confidence is unjustified. The existence of the former group would be predicted from the research of Gooday et al (1993). Students gained in confidence about teaching science and technology during their training course, but they did not necessarily gain much in understanding of the concepts of science and technology. There is a cliché that one never really understands something until one has taught it, but this needs some elaboration and qualification. If a teacher knows what concept s/he wishes a learner to acquire and if through teaching it her/his own understanding of that same concept becomes deeper, then helping the learner has also helped the teacher. However, there must be concern about that teacher in this research who found that every time she taught any science or technology her confidence increased and thus she concluded that her understanding of the ideas had increased also. An increase of confidence is not necessarily accompanied by increased understanding.

Just as disconcerting is an unjustified lack of confidence. In some teachers the absence of some paper qualification, or perhaps some gender-related lack of self-esteem, has resulted in a lack of confidence about teaching science and technology. But these teachers have, through intellectual curiosity and professional conscientiousness, acquired for themselves an adequate basis of conceptual understanding.

The different relationships between confidence and understanding mean that no single type of professional development help will be appropriate in all cases.

■ What effects do low confidence and low understanding have on teaching?

The simple answer is that teachers cope somehow; some avoid teaching science and technology if it is at all possible; others teach in whatever way avoids anticipated problems.

The research did not involve classroom observation, therefore we cannot provide any direct description of teacher performance in the classroom. Some relevant data were collected, however, in Phases 2 and 3 of the project, when teachers described their activities, problems and successes, their pupils' reactions and how they themselves felt about their teaching. They made predictions about how effective their teaching would be, and made self-appraisals of how effective their teaching had been. This gives us some basis for comment on how low confidence and understanding influence classroom practice.

Low confidence about science/technology teaching can have a number of effects. These include:

- teaching as little of the subjects as one can get away with
- compensating for doing less of a low-confidence aspect by doing more of a higher-confidence aspect; in practice this can mean
  - stressing the process aims in science rather than the conceptual development aims
  - doing more biology/ nature study and less physical science
  - spending more time on construction work in technology and less on design; more on social aspects and less on control technology
- placing heavy reliance on kits, prescriptive texts and pupil work cards – where pupils have to follow clear instructions step-by-step
- emphasising expository teaching and underplaying questioning and discussion: 'keeping the progress of the lesson under control'
- avoiding practical work and any apparatus that could go wrong
- depending on the assistance of colleagues and outside experts.

We are aware in providing such a list that we may be thought to suggest that all these things are reprehensible – and clearly they are not. Each response can be a reasonable one to a difficult situation, particularly if things are made worse by time pressures.

Awareness of inadequate understanding of content can lead to a number of the same coping strategies given above. For example, using prescriptive work cards in science can reduce the need for interventions to encourage cognitive advance; in technology the making of models can become something of a drug – the pupils are 'doing something they enjoy', they are being kept occupied rather than engaging with their teachers in discussion of design ideas, etc. Physical activity is seen as a very attractive option when mental activity might be hazardous for the teacher. Expository teaching can minimise the occurrence of 'awkward' questions from pupils; selecting particular topics can avoid the areas of least teacher understanding. Over-dependence on a standard response to questions about content can also occur: 'That's a very good question. How would you set about finding an answer?' This seems to us an ideal response on occasion; pupils are very quick to realise when it is the only response that a teacher feels able to give.

The above says nothing about those situations where teachers are unaware that their understanding is less than adequate. It is then that teachers can develop

ideas in pupils which are quite simply wrong or, rather more subtly, are unhelpful in some way for later conceptual development. Furthermore, there are the missed opportunities for helping pupils' progress in understanding.

It was evident that teachers adopted ways of teaching which made best use of their general pedagogical skills, whilst avoiding situations where their confidence was low. We do, however, need to distinguish between teaching for survival and teaching in ways that are unhelpful to the development of understanding in pupils. The latter cannot easily be defended.

How should initial training be changed?

The research in Phase 4 supports the view that the time is ripe for Teacher Education Institutions (TEIs) to review initial training for the teaching and management of all aspects of science and technology within the primary school. The time made available for science and technology appears inadequate and ways should be sought to increase it; there is a need to review the selection procedures for entry to primary training, particularly with regard to the qualifications in science subjects that candidates should possess; it seems desirable to revise existing policies on optional courses within BEd degrees – options in science and technology should be made attractive to students who perceive they have weaknesses in these areas. Tutors in science and technology are already examining with care (a) the relative priority that should be attached to content and process aims within their courses and (b) the means for effective differentiation in response to the varying backgrounds of their students. On the basis of our research we would like to make a contribution to their discussion of the methods by which their aims may be effectively achieved.

If the purpose of teaching science to young pupils is conceptual development, ie the understanding of progressively more general, abstract and powerful ideas, then this suggests that certain teaching methods will be more appropriate than others. Such methods may differ in detail, but they have important features in common: they require that pupils' pre-existing ideas be taken seriously into account, they stress attentive listening by teachers to what pupils have to say within carefully structured discussion and they insist that meanings are not merely transplanted from teacher to pupil but are actively constructed by the pupil. All this suggests a general strategy of science teaching which does not abandon practical activity, but which justifies practical activity only to the extent that it provides fertile contexts for the advancement of pupils' thinking from the concrete to the abstract. The model of science teaching becomes re-defined as one centring on the eliciting and negotiation of meanings (Sutton 1992).

If we want development in teachers' understanding of science concepts should the initial training of teachers – and perhaps aspects of inservice education provision – follow some kind of conceptual change model? More generally, if we accept that teachers come to their training already possessing ideas about the nature of teaching and learning (and how could it be otherwise?), does this mean that teacher education should be re-interpreted as a process of inducing change in pedagogical concepts (see page 5/6)? Should training for pedagogical conceptual change then also follow a similar model?

It does not automatically follow that a method appropriate to young learners

will be equally appropriate for mature learners. Perhaps, for example, adults only have to go through the conceptual change model once or twice to understand the principles involved, and then by some reflective process can come to appreciate its applicability in other areas; that is, they don't have to develop all the necessary concepts in this way. It was interesting that in the science departments of some TEIs work was underway to explore the use of this kind of approach. The inservice work of the Summers and Kruger team is based on similar principles – see, for example, their 1993 report. There seems little doubt that it is valuable for teachers to come to an understanding of how conceptual development in pupils can come about through enactive personal involvement in the same kind of process themselves.

Whether the same kind of argument applies to the development of pedagogical concepts is more problematic; perhaps pedagogical concepts are distinctively different in type from science concepts. The course documentation from TEIs indicates strong belief in some kind of teaching model, such as the one known as SPIE, which involves Specification of aims and/or objectives, Planning of appropriate activities, Implementation of the activities and Evaluation of the success of teaching. This model is adopted both as the basis of the planning of the teacher education courses themselves and as the prescribed model for students to plan programmes of teaching for their school placements. Whether SPIE and conceptual change models are incompatible or complementary is worth examination. If SPIE insists on objectives in strictly behavioural terms, there would seem to be a real difference; in this case SPIE requires observable outcomes, whereas conceptual change models are concerned with the development of mental organisations or schemata. If however, SPIE specifies concept development as an aim then it tells people nothing useful about the types of activity which are likely to bring about that development; in this case a model for conceptual change seems to be a necessary supplement to the broad planning cycle.

It is important to avoid the easy assumption that concepts in relation to technology are of the same kind as concepts for science. It looks as if in future we will talk in Scotland about the development in pupils of technological *capability*. It is clear from the SCCC policy document that the elements of technological capability that are described (perspective, confidence, sensitivity and creativity) encompass conceptual development ('...an appropriate base of technological concepts ...[for].... understanding of the world around them'). They are by no means confined to conceptual development, they include also feelings/attitudes and practical skills. Insofar as the purpose of technological education for pupils is conceptual development, and insofar as the training and professional development of teachers is about enhancing the conceptual aspects of their own technological capability, the above remarks about conceptual change would seem to be relevant.

In Chapter 2 we described the research method devised for Phase 2 of this research. We claimed that 'collaborative explanation' had some success as a method of diagnosing the level of understanding of teachers; in addition we showed that the process had significant effects in developing teachers' understanding. It is reasonable to claim that a research method to *diagnose* also worked as a teaching method to *develop*. In addition, in the vast majority of cases, the diagnosis and development of teacher understanding was achieved alongside

an enhancement of teacher confidence. Collaborative explanation is likely to be an effective method within teacher training.

More generally the most promising ways ahead would seem to centre teacher training and professional development on *pupils'* understanding of concepts in science and technology and on effective ways of developing that understanding. Teachers will be able to apply the messages contained in this process to the development of their own understanding. Whatever is done within initial training for the primary teachers of the future, there remains a pressing need to supply professional development opportunities for mature, experienced teachers. This is the central concern of our final issue.

What professional development of teachers is needed?

In an earlier issue we discussed how teachers manage when they do not have the knowledge or the help that they feel they need to teach primary science and technology with confidence. It has become clear that however hard teachers work in order to 'cope' there is no doubt that the pupils' education suffers. This point adds urgency as we now turn the discussion to what help to provide and how to provide it. Furthermore, some teachers cope so well that they may not realise that their pupils are being 'under-sold'; others may have a limited view of what primary science and technology mean in practice. Thus the figures given in the discussion below may well be an underestimate of the scale of the help needed.

Sources of information

Whilst information about the help teachers needed in relation to science and technology was sought directly in certain parts of all the first three phases of the project, it is also possible to infer needs from other parts of the data. Both sources are used in this discussion. It is relevant, also, to recall that, as pointed out at the beginning of Chapter 4.5, the answers obtained from teachers on the subject of help required seemed to depend to some extent on the context and on the way in which they were asked. When talking about particular pieces of teaching the concerns were, quite understandably, with the practical difficulties of class management and whether or not the equipment had been easy to obtain and whether it had worked. When talking about possible rather than actual teaching, in Phases 1 and 2, inservice training and printed materials were at the forefront. However in all three phases there were between a quarter and one third of teachers who expressed in open responses a need to increase their own understanding, particularly in physical science and in technology.

There is need to proceed with caution, however, in inferring, for instance, that lack of confidence in teaching certain topics or ideas will be improved by increasing background knowledge. As we have seen on page 202, the two do not invariably go together, neither is there an established cause–effect relationship. Also there is evidence from research in another area of the primary curriculum, the teaching of foreign languages, that confidence is not necessarily related to subject knowledge. Whilst primary teachers have little science in their background (21% only with at least one Higher Grade pass), the proportion with a foreign language at Higher Grade is 55% and yet few feel confident about primary school foreign language teaching. They have *general* pedagogic knowledge relevant to primary school teaching, but lack the pedagogic *subject* knowledge (see p 5/6).

A message coming through our data indeed suggests that in science there is the same need for pedagogic subject knowledge – for knowing what teaching primary science and technology means in action (how to do it) – but that the position is further complicated by the need for equipment and materials for practical work, the supply and maintenance of these materials and the classroom management that their use requires.

In this section, then, we must be concerned with the whole range of kind of help which teachers have themselves identified as their needs and which our other research evidence suggests they need. In doing this we first look at the scale of the problem – how many teachers needing help are we talking about? – since this must be taken into consideration in proposing any realistic solution. We then look again at what teachers have suggested might help and from this offer some suggestions of possible approaches.

The scale of the problem

In Chapter 4.1 we gave percentages of teachers reporting varying degrees of confidence in teaching different aspects of science and technology (Table 4.9). This shows that the proportions of teachers depending on guidance from others, or needing help with their own understanding, were:

Understanding living things	35%
Understanding energy and forces	58%
Understanding Earth and Space	35%
Understanding technology	59%
Science processes	33%

If we make the assumption that the same teachers are included in many of these groups, that those requiring help with technology will include those requiring help with energy and forces, for example, then we have about 60% of the sample in need of help with at least some aspect of science and technology. As our sample was one drawn from a random sample of schools across Scotland and the characteristics of the sample closely reflect those of the population of primary teachers (see page 30), it is reasonable to extrapolate to the total primary teaching force (of about 22,400), which suggests that about 60%, or 13,440, need some further professional development in science and technology.

The size of this task is only slightly less alarming if we consider only those who declared themselves in the lowest category of confidence (needing help to develop their knowledge and skills). In this case the figures are

Understanding living things	11%
Understanding energy and forces	24%
Understanding Earth and Space	9%
Understanding technology	29%
Science processes	8%

On this basis about one quarter of the teaching force, or 5,600 teachers, require help to develop their knowledge and skills in at least one of the areas of science and technology which they are expected to teach.

It is interesting to note, from page 40 in Chapter 4.1, that there is a significant difference between the confidence of teachers of P3 and P4 and those who teach P6 and P7 with regard to all aspects except 'living things', but not in relation to general pedagogic skills. Might this mean that inservice help should be directed preferentially at teachers of lower age pupils, or is there some explanation of the data other than there being a real difference between these groups' confidence? It is certainly possible that the teachers with more confidence in science and technology are assigned to the older pupils. At the same time it may be that the greater confidence of the 'upper' teachers comes from having to cope with the more advanced work, and that through coping, they become more confident, even though no more knowledgeable, than their colleagues teaching 'lower' classes. (The research of Gooday et al (1993) supports this possibility). As we have emphasised, confidence is not the same as competence; the research has not provided information about the latter. A further explanation may be that, even though all teachers responded to the same statements, there was some element of referencing to the pupils they teach. More of the statements would seem to be out of the reach of their pupils in the judgement of the lower teachers and this may well have affected their feeling of how confident they would be to teach these ideas. For these reasons there does not seem to be a convincing argument for directing help at teachers of the lower age groups rather than at all primary teachers.

The kinds of help needed

A number of the requests made by teachers at various points of the research can be brought together under the heading of subject-related pedagogy. These include the many pleas for someone to come into their classroom and show them ' how to do it'. Such requests could well indicate a lack of first-hand experience, both in their own education and in their professional training, of what primary science and technology should look like in action. Teachers also asked for help with particular and crucial aspects of teaching, such as with asking questions to stimulate their pupils thinking, with ways of 'moving them on', with handling the questions pupils ask and with managing a class during practical work.

Such concerns spread over into planning when teachers expressed uncertainty about how much science is needed ('is one big topic a year enough?'), how much practical work there should be within a science topic and whether just 'doing' and 'making' are enough. Requests for stage-related activities indicate uncertainties about the nature of development in science and technology and how far to go at each stage. Some teachers seemed to be uncertain about the criteria to be applied in judging success, in particular the extent to which these should go beyond 'enjoyment'.

As documented in Chapters 4.1 and 4.5, uncertainties about topics, activities and depth of treatment can be spelled out into long lists, which must seem overwhelming to many primary teachers. In reality, however, they can be seen to be related to the basic understanding of the aims of teaching primary science and technology and to the appreciation of how children learn (Harlen and Osborne, 1985). The publication of the 5–14 *Guidelines on Environmental Studies* (SOED, 1993) has now provided a full statement of the aims of teaching these areas of the curriculum. The timing of our research meant that teachers would not have had

chance to absorb the messages of the guidelines at the time of responding to our questions. Indeed other research (Malcolm, Harlen and Byrne, 1995) suggests that it will be 1995/96 at the earliest that the *Environmental Studies* guidelines will begin to have an impact on practice.

However, although the aims and attainment targets in the guidelines provide a means of checking consistency of teaching methods and activities with overall purposes, teachers still need help in developing appropriate skills to handle questions and advance pupils' ideas. Some help of this kind will be available in the publication *Taking a Closer Look: Science* (SCRE, 1995), which is concerned with helping teachers' formative assessment of science, that is, assessment that enables teacher to know where pupils are in their development and what the next steps should be. When asked directly about assessment and record keeping in the Phase 1 questionnaire, teachers indicated that these were the most difficult of the teaching activities listed. That little was said in later phases of the project probably reflects the fact that the 5–14 guidelines for *Environmental Studies* were not being implemented and the requirement for assessment, either formative or summative, had not been encountered to any extent.

Whilst some aspects of the help teachers need are being put into place, some of the more immediately impeding problems remain to be resolved. There were frequent requests for help in regard to equipment and materials for practical work. Teachers pointed out that a single session of practical work would require hours of searching, collecting and checking equipment. The requests for a technician in the school indeed seem reasonable if, say, three-fifths of the 25% of curriculum time for environmental studies is devoted to science and technology. This means 15% of the time of each class, which is rather more than the amount which at the secondary level justifies a technician for every 300 pupils. The arguments put forward for technician help (SOED, 1994b, para 4.10) could be applied equally to primary schools. Thus, unless there is some quite drastic reduction in the expectations of the amount of practical work in science and technology in the primary school, it is hard to see how teachers can be expected to implement 5–14 guidelines adequately, without more non-teaching time or some technician help. The result of 'managing' or 'getting by', as we have seen, takes its toll on pupils' experiences.

The requests which teachers have made for detailed accounts of what to teach and for explanations of content can be considered as being related to the need for better personal understanding of the concepts of science and technology, or 'big ideas' as we have called them in this research. A teacher lacking understanding of these ideas may either request help to improve his or her understanding or may ask for such detailed guidance to follow that there is little dependence on teacher thinking. The latter approach cannot cater for pupils' individual paths of intellectual development nor foster creativity and genuine problem-solving skills, for which unexpected suggestions have to be encouraged and tried. However this does not mean that some examples of activities, described in detail are not valuable. As part of their own development it builds confidence to have successfully tried out a few 'worked examples' of activities, particularly if these include how to bring together what pupils have found out, how to elicit their ideas about what it means, about applying new ideas and, in the context of technology, how to evaluate both processes and products in terms of the initial

problem. Trying out some worked examples of this kind would be particularly helpful in the context of inservice work where experience is discussed and alternatives can be suggested for teachers to try as they move to use the material more as ideas and less as instructions to follow. It would certainly seem helpful to provide some examples of activities related to key ideas which could be contextualised by teachers to suit topics chosen for their pupils.

Findings in Phase 2 (p96) suggested there would be value in grouping the key ideas into (a) those commonly understood by teachers, (b) those less commonly understood but in which understanding is readily developed and (c) those not commonly understood and in which understanding is difficult and time-consuming to achieve. An effective grouping of this kind is to some extent achievable by a desk-based analysis informed by existing research into what teachers (and pupils) find difficult; it might well require further research to validate the categorisation recommended. Such an approach would allow some targeting of inservice provision on the areas of understanding where the need was greatest; when resources are limited, there seems little justification in focusing entirely on ideas in groups (a) and (b).

The Phase 2 investigations have also enabled the identification of types of misunderstandings and of possible reasons for them. If extended, the results of such investigations could be used to guide the production of inservice activities or print-based help specifically addressed at helping *teachers'* own understanding of the big ideas. The general findings suggest that priority areas for this kind of development would be energy and forces and technology. However the value of providing any one kind of help is magnified if it is in the context of supporting the range of planning, teaching, assessing and evaluating activities which are involved in tackling any topic. How to provide such help is the topic to which we now turn.

Ways of providing help

A useful starting point for discussion of this topic is the information gathered in Phase 1 about the inservice courses in science, technology, or environmental studies more generally, attended by teachers and their reactions to them. We found that a small proportion (less than 4%) of teachers had, in the past five years, taken an award-bearing course which included these subjects. A further 11% had attended non-award-bearing courses of more than one day's duration within the same period. The remaining 85% had no recent inservice experience other than, if anything, single sessions of one day or less. In Phases 2 and 3 teachers commented on the courses they had attended, of whatever length, and on their needs left unaddressed. From these comments we were able to identify pointers to the kind of provision favoured and not favoured by teachers.

Not surprisingly teachers wanted inservice to be tailored to their needs and relevant to the stage they were teaching. They wanted a series of meetings, allowing time to try out ideas between sessions; they wanted practical workshops, offering 'hands-on' experiences relevant to their own classroom opportunities; they wanted help in their own classrooms, not to take over the teaching, but to give ideas and support which would enable them to increase their own competence. Above all, they wanted experiences which would increase their confidence in relation to their own knowledge and their ability to teach effectively.

No doubt teachers would value experiences of a more general kind, but for the 60% who need help their priority is for what is immediately relevant in their classrooms. This is one of several factors which point to the school as being the best focus for the provision of help, rather than the college or teachers' centre. Conditions for relevance of content, regularity of meetings, appropriateness of resources available, etc, are assured by school-based or cluster-based inservice. It is perhaps worth noting in this context that the only school factor found to be linked with higher achievement in the AAP tests (see page 62) was the existence of a school policy, which may be a surrogate for the in-school discussions of aspects of teaching which need to be included in a written policy. This is supported by other work on the implementation of change which indicates that the whole school approach is far more effective than providing courses which are attended by individual teachers.

Thus one major implication for practice arising from the research is that inservice appears to be potentially more acceptable and more effective when it is provided at school level. This may mean local school group level for small schools and where clusters of schools are already working effectively. However, whilst the structure may exist, the substance to be communicated through the structure of school-based inservice does not; hence the description of this route as being 'potentially useful'. If this potential is to be realised there is a need to bring together existing and new materials as a basis for school-based inservice workshops. This workshop material needs to cover all topics from school policy development, to the supply and organisation of equipment, the selection of classroom print-based materials, the interactions between teacher and pupils and interactions among pupils. An important element would be the discussion by teachers of their own understanding of key ideas, supported by clear descriptions of their applications in contexts such as the ones used in Phase 2 of the research. In such materials the medium should help the message and the predominant mode should be active, taking the opportunity to distinguish between active learning and practical work. With materials of this kind available it may well be possible, as some teachers pointed out to us, that the expertise to help others can be found within the school, or group of schools.

Summary of points discussed

We have interpreted the research findings to mean that, in relation to the issue of whether teachers' confidence about science and technology presents a problem, there is indeed a real problem which cannot be dismissed as inevitable or one that time will solve. Similarly we have concluded that the proportion of primary teachers who do not themselves understand the concepts they have to teach must be seen as a problem. Depending on the assumptions made about what level of understanding is adequate, and to some extent on whether the judgement of understanding is made by the researchers or the teachers, up to 60% of primary teachers need help in some aspects of understanding in science and technology and 30% need a good deal of help.

Underlining the problematic nature of low confidence and understanding are the findings of how teachers manage without adequate confidence and/or understanding. The strategies used to cope in these circumstances result in restricted and often unbalanced opportunities for pupils to learn science and technology. Thus without addressing the problem it will not be possible for a large proportion of primary pupils to experience the broad, balanced and progressive curriculum that 5–14 potentially represents.

The research has shown, however, that confidence is not solely determined by understanding; the two were found to go together in about two-thirds of the teachers. Confidence was also affected by experience of inservice training, by inadequate support from materials and with the provision and maintenance of equipment, by a feeling that the curriculum was overloaded and by lack of a clear idea of what teaching science to primary children should be. Thus the issue of how to improve primary science teaching is not simply concerned with increasing teachers' subject knowledge but with providing help with subject-related pedagogy and with the management of equipment, among other things. Interpretation of findings about how help might most effectively be provided point to treating the school as a unit and ensuring that each school has access to a member of staff with subject expertise and time to share it in helping other staff as individuals and through the collective development of a school policy.

The findings from enquiries into initial teacher education courses raise serious concerns about the adequacy of the preparation of new primary teachers for developing understanding in science and technology in pupils. Issues surround the dual task of developing student teachers' own understanding and providing them with the skills and knowledge to help pupils' understanding. Consideration ought to be given to employing a conceptual change model in developing pedagogical skills as well as in developing conceptual understanding. At the same time, further consideration needs to be given to the differences in learning of adults and primary pupils.

7 Implications

In the previous chapter we discussed a wide range of issues emerging from the research which have an impact on the further development of science and technology teaching in primary schools. In this final chapter we bring together some implications for action for five different groups concerned with science and technology education: headteachers and school management teams; teachers; policy-makers; teacher educators; and researchers. The points are listed without enlargement since the supporting evidence and argument is contained in earlier chapters.

Implications for headteachers and school management teams

- To produce and keep under review a whole-school policy for science and technology, taking into account the national guidelines for Environmental Studies. Such a policy would require, amongst other things, year plans which identify for the coming session the science and technology to be encountered by pupils (as components of environmental studies provision) and show how they are related to the attainment outcomes, key features and foci of study in the guidelines.

- To assist all staff to identify their professional development needs in relation to the science/technology programme they have to provide.

- To plan and co-ordinate the provision of school-based or cluster-based professional development activities, making use of external agencies as appropriate.

- To appoint from within the staff subject leader(s) or co-ordinator(s) whose responsibilities include science and technology.

- To ensure the acquisition and accessible storage of adequate learning resources and materials for practical activities.

- To facilitate, whenever possible, the provision of technician/auxiliary help to support the teaching of science and technology.

- To ensure that staff have opportunity to discuss and share their problems and solutions in teaching science and technology.

- To encourage the development of confidence in individual teachers by recognising and valuing developments in their capability.

Implications for teachers

- To plan teaching programmes for science and technology, consistent with the school policy, which take account of the progression of pupils' conceptual understanding.

- To have in mind, for each activity/lesson, the development in pupils' knowledge, understanding and skill that is intended.

- To re-examine the balance in their work between practical activity and discussion with pupils of the meaning of their findings.

- To reflect critically on the extent to which it is necessary to develop their own understanding and attempt to find opportunity for that development.

- To recognise that no-one is able to answer all pupils' questions and that this is not in any case desirable, but that they can develop skills of using all pupils' questions productively.

- To make a start with science and technology teaching, even if confidence is initially low, for not only will their general knowledge and pedagogical skills enable them to be more effective than they think, but only in this way will they realise what is involved and identify their own developmental needs.

Implications for policy-makers

- To recognise that the current situation is seriously restricting the science and technology development of a large proportion of pupils and that the issues involved urgently need to be raised higher on the educational agenda.

- To accept that the achievement of the educational aims of 5-14 within any reasonable time-scale means a high level of support for teachers in the area of science and technology teaching.

- To provide adequate funding and support over an extended period for a programme of whole-school development in science and technology teaching and the training of science co-ordinators.

- To develop partnerships amongst education authorities and between authorities and teacher education institutions to deliver a training and development programme, tailored to a range of teacher needs and which avoid duplication of effort.

- To use findings of research into teachers' misunderstandings to target in-service and other help where it is most needed.

- To continue and extend the production of print-based and other materials to support teaching, and which include background information at the teachers' level.

- To provide technician/auxiliary support to primary schools.

- To re-examine the role of specialism in primary school curriculum delivery.

- To review the Memorandum on Entry Requirements and the Guidelines for Teacher Training in relation to the qualifications and the selection of candidates for primary training.

- To identify science and technology teaching as a priority for further research and for development based on research.

Implications for teacher educators

- To consider how best to provide appropriate initial and in-service education for the teaching and management of all aspects of science and technology within primary schools.

- To ensure that there is sufficient time available for science and technology within initial training to prepare student teachers to teach 5–14 effectively.

- To review the relative priority to be attached to content and process aims within initial training to teach science and technology in the primary schools.

- To review course content in relation to catering for conceptual change in both the education of teachers and the teaching of pupils.

- To examine the selection procedures for entry to primary training, particularly with regard to the qualifications in science subjects that applicants should possess.

- To review policy with respect to optional courses within programmes of initial training in order to ensure that these are attractive to students wishing to develop their capabilities or develop a specialism in the teaching of science and technology.

- To develop and provide school and cluster-based in-service support in partnership with education authorities and other agencies.

- To extend their provision of longer award-bearing courses, with increased emphasis on those which enhance teachers' understanding of content.

Implications for researchers

- To identify, perhaps along the lines of the 'big ideas' approach in this research, the conceptual development in the science and technology outcomes of the national guidelines.

- To monitor the shifts in teacher confidence over time; in particular to include in the 1996 AAP science survey a repeat of the questionnaire used in phase 1 of this research.

- To evaluate the quality of pupils' learning experiences in science and technology against criteria drawn from the national guidelines.

- To seek to illuminate any relationship between teacher capability in science and technology teaching and pupil achievement.

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Questionnaire for Teachers of Pupils in P3, P4, P6 and P7

This questionnaire has been sent to primary schools involved in the AAP Science Survey but relates to a separate SOED funded research project concerned with the teaching of science and technology in the primary school. It was sent with the permission of your Director of Education.

The aims of the project are to explore problems primary teachers encounter in teaching science and technology that are related to their background in these subjects, and to identify any changes in teacher training and support that are needed.

The information you provide will be treated in the strictest confidence and nothing will be used in a way which identifies individuals. We ask for your name only because we would like to speak to some teachers in the next phase of the project. Please seal the completed form in the envelope and return it to your Headteacher.

BACKGROUND INFORMATION

Name of teacher .....

1. *Please tick*
   Male ☐ Female ☐

2. Stage taught: *(Please tick more than one box if your class contains pupils at these stages)*

   P3 ☐ P4 ☐ P6 ☐ P7 ☐

3. Do you have responsibility in the school for a particular curriculum area(s)?

   Yes ☐ No ☐

   If Yes, please say which area(s) .....

4. About your teaching qualification —

   (a) When did you qualify?

   0–4 years ago ☐ 5–11 years ago ☐ 12–25 years ago ☐ 25+ years ago ☐

   (b) What was the qualification? .....

   (c) Where did you study for it? .....

5. About your qualifications in science —

   (a) What areyour pre-service awards in science subjects?

   .....

   (b) Have you, in the last five years, attended an in-service course of more than one day's duration concerned with teaching science or environmental studies?

   Yes ☐ No ☐

   If Yes, please give the date, title, duration and location of the course and say whether it resulted in any award.

   .....

   .....

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6. Your employment experience —

(a) Have you taught in a secondary school?

Yes ☐ No ☐

(b) Have you been employed for a year or more outside teaching?

Yes ☐ No ☐

(c) Please indicate the number of years you have been teaching.

0–4 ☐ 5–11 ☐ 12–25 ☐ 25+ ☐

TEACHING ACROSS THE CURRICULUM

7. Some teachers are more confident in their knowledge and teaching skills in some areas of the curriculum than others. Please give an honest estimate of how you feel in general about teaching the following, rating each as follows:

1 Fully confident in my knowledge and skills
2 Confident with a little guidance from others
3 I can manage but depend on advice from others
4 I need help to develop my knowledge and skills in this area

	1	2	3	4
English	☐	☐	☐	☐
Mathematics	☐	☐	☐	☐
Science	☐	☐	☐	☐
Social subjects	☐	☐	☐	☐
Technology	☐	☐	☐	☐
Health education	☐	☐	☐	☐
Information technology	☐	☐	☐	☐
Art	☐	☐	☐	☐
Music	☐	☐	☐	☐
Physical education	☐	☐	☐	☐
Religious education	☐	☐	☐	☐

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8. How confident do you feel that you have the knowledge needed to help pupils develop understanding of each of the following kinds, quoted from the 5 – 14 Guidelines for *Environmental Studies*? Please rate them 1 – 4 using the same criteria as in question 7.

	1	2	3	4
The structure and functions of the major parts of the human body as they relate to the processes of movement (muscles, bones and joints) and nutrition (teeth and digestive system)	☐	☐	☐	☐
The functions of the major parts of the human body as they relate to the processes of respiration, excretion, sensitivity and reproduction	☐	☐	☐	☐
Simple food chains based on energy from the sun	☐	☐	☐	☐
The main distinguishing features of vertebrates (fish, amphibians, reptiles, birds and mammals), major invertebrate groups (worms, molluscs, arthropods such as insects, spiders and crabs)	☐	☐	☐	☐
The main distinguishing features of flowering (mono-cotyledons, dicotyledons) and non-flowering plants (algae, mosses, lichens, ferns, fungi, conifers) and micro-organisms (bacteria and viruses)	☐	☐	☐	☐
Adaptation to the environment over a period of time, leading to an understanding of the process of evolution and the survival or extinction of species	☐	☐	☐	☐
Sound from a variety of vibrating sources, eg *tuning fork, violin string, radio and TV speaker*	☐	☐	☐	☐
Construction of battery operated circuits to operate, *eg bells, buzzers, lamps, warning lights*	☐	☐	☐	☐
Renewable and non-renewable sources of energy	☐	☐	☐	☐
Potential and kinetic energy	☐	☐	☐	☐
Mirrors and reflections, including curved mirrors	☐	☐	☐	☐
Force of gravity	☐	☐	☐	☐
Simple relationships between the ways people live and the technologies they use in different communities and environments	☐	☐	☐	☐
Ways in which individuals can use technology to change their own environment and lifestyle	☐	☐	☐	☐
Ways in which energy is converted and materials can change state eg burning fossil fuels to create electricity	☐	☐	☐	☐
Simple relationships between the way people control their movements and the way control technology helps us to produce automated systems to control our environment	☐	☐	☐	☐
How control technology can be used for specific purposes in different situations, eg computer interface to control lights and motors	☐	☐	☐	☐
The different stages of the design process and strategies they can use within these stages	☐	☐	☐	☐

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The effectiveness and drawbacks in the design of local environments for different groups of users, eg the supermarket for someone in a wheelchair	☐	☐	☐	☐
Earth's magnetic field and the compass	☐	☐	☐	☐
The planets of the solar system	☐	☐	☐	☐
The motions of Sun, Moon Earth and planets and related effects, *eg day/night, seasons, phases of the moon*	☐	☐	☐	☐
The water cycle (in simple outline) introducing water as a gas, melting, freezing, evaporation, condensation	☐	☐	☐	☐
The structure of the Earth; the Earth's crust and processes which led to the formation of main features in it, *eg formation of different types of rock, fossils*	☐	☐	☐	☐
Natural and manufactured materials and simple examples of recycling	☐	☐	☐	☐
Fossil fuels; occurrence, combustion and effects of emission of 'greenhouse gasses'; methods of avoiding/overcoming atmospheric pollution; other uses (outline only)	☐	☐	☐	☐

9. Please rate, in the same way, how confident you feel in helping pupils to do the following:

	1	2	3	4
Identify relevant questions to investigate	☐	☐	☐	☐
Decide on appropriate strategies, procedures, sources of information, evidence and resources/equipment to carry out an investigation, justifying choices and monitoring for possible unfairness	☐	☐	☐	☐
Propose methods and categories for recording and reporting findings and outcomes of enquiries	☐	☐	☐	☐
Observe events, noticing sequences and changes	☐	☐	☐	☐
Estimate, measure and draw accurately, selecting appropriate units and measuring devices	☐	☐	☐	☐
Record evidence in a variety of appropriate ways, including making labelled and annotated sketches; constructing spreadsheet tables, databases, pie charts, line and bar charts, making annotated sequences of photographs/illustrations; writing organised reports	☐	☐	☐	☐
Draw conclusions and justify them with reference to evidence, *eg about conditions necessary for photosynthesis*	☐	☐	☐	☐
Make predictions using knowledge and information gained in several different contexts, *eg about the effects of effluent on life in rivers*	☐	☐	☐	☐
Make and test hypotheses, *eg about the effect of the removal of a link in a food chain*	☐	☐	☐	☐
With guidance from the teacher, recognise reliable evidence	☐	☐	☐	☐

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10. **Teaching science and technology involves many professional skills, some of which you may find more difficult than others. Please give your estimate of how difficult, in general, the following are for you in terms of the following criteria:**

1 Not at all difficult
2 Sometimes a little difficult
3 Usually quite difficult
4 Very difficult

	1	2	3	4
Deciding concepts to be developed in an activity	☐	☐	☐	☐
Deciding process skills to be developed in an activity	☐	☐	☐	☐
Obtaining and maintaining equipment	☐	☐	☐	☐
Ensuring the equal interest and participation of girls and boys	☐	☐	☐	☐
Matching activities to pupils' development and needs	☐	☐	☐	☐
Introducing a new topic	☐	☐	☐	☐
Responding to pupils' questions about content	☐	☐	☐	☐
Explaining ideas to pupils	☐	☐	☐	☐
Organising and supporting practical work	☐	☐	☐	☐
Using questioning skills to stimulate pupils' thinking	☐	☐	☐	☐
Continuous (diagnostic) assessment in relation to concept development	☐	☐	☐	☐
Continuous (diagnostic) assessment in relation to process skills	☐	☐	☐	☐
Record keeping	☐	☐	☐	☐

11. Please indicate what help, if any, you need in relation to your understanding in science and technology and what form this might take.

Your help in completing this questionnaire is very much appreciated. Thank you. ☐

Please seal it in the envelope provided and give it to the Headteacher for return to SCRE with other forms in the pre-paid envelope.

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WH/JJ
20.5.93

SCIENCE AND TECHNOLOGY TEACHING AIDE MEMOIRE

Name: School: Date: Topic:

1 In general, how happy were you with this bit of teaching?

Very happy Quite happy Quite unhappy Very unhappy

2 If there were any problems, were they connected with any of the following?

Time (to prepare)	Yes	No
Equipment/materials	Yes	No
The subject content	Yes	No
Pupil difficulties	Yes	No
Classroom size/facilities	Yes	No
Class management	Yes	No

Other (Please specify) .....

.....

.....

3 Notes about any problem/difficulty encountered.

4 Notes about any particular help it would have been useful to have at any time during the teaching.

CONDENSED VERSION OF PHASE 4 SCHEDULE

PTUCST PHASE 4

Name:
Title/remit:
Institution:

Areas of involvement:

ITT PGCE		A
ITT BEd		B
INSET	Award-bearing	C
INSET	Short courses	D
Research/Development		E
Science and/or Technology		

Notes:
1 As much factual information as possible to be taken from course documents before visit.
2 Three main concerns: nature of current provision
changes in pipeline
changes wished, but not planned.

A and B PGCE and BEd Number on course?

1 CURRENT PROVISION

Within college: total time to Environmental Studies?
fraction of this to (a) sci and (b) tech?
core or elective?
'distinct element'?

In-school: assignment/project?

Fieldwork: how much? where? for whom?

Assessment?

2 AIMS What priority is given to the following for science/technology?

- understanding of nature/processes
- understanding of content
- development of teaching skills
- classroom management strategies
- materials and resources
- confidence and attitudes.

3 CONTENT What content is covered?
How is coverage decided?

If deficit in students' content knowledge is revealed, what do you do?

Consider these six topics (ie topics covered in phase 2). Does the course develop understanding of the science ideas in these? To a greater depth than required in pupils?

4 METHODS Numbers in sections?
Lectures; laboratory sessions; seminars; workshops; seminars; other.

Are the methods designed for adult learners — or to model classroom methods? Or?

What time/emphasis is placed on students' own understanding? And on activities appropriate to pupils?

5 ADEQUACY/CHANGE

PGCE or BEd — which is the better preparation for teaching science/technology? Why?

How satisfactory is current provision (quantity, aims, coverage, methods)?

What changes are being planned?

What changes are not in pipeline that *you* think are desirable?

C and D INSET/Professional Development

Names of courses available — both award-bearing and short ad-hoc courses — last session? Numbers of teachers involved?

Then apply questions above (Aims, Content, Methods, Adequacy/Change), modified as appropriate, *either* to general provision, *or* to courses the interviewee is involved with.

Add As 5–14 Science and Technology implementation proceeds, what will be the main implications for professional development of teachers?

What is the most significant PD currently supplied by other agencies?

How would you like *their* provision to develop?

How can the needs of primary techers (in relation to science (technology) best be met?

E RESEARCH and/or DEVELOPMENT

What research projects, or materials development projects – science and/or technology – are you involved in?

Any others you know are taking place?

People? Location? Publications? References?

What is *not* happening that should be?

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